A DECISION SUPPORT FRAMEWORK FOR SELECTING FEASIBLE COASTAL PROTECTION MEASURES IN THE REPUBLIC OF MALDIVES

ENCI790

A THESIS SUBMITTED TO THE UNIVERSITY OF CANTERBURY IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN CIVIL ENGINEERING

By

ABDULLA THASLEEM ABDUL HAKEEM

Department of Civil and Natural Resources Engineering,

University of Canterbury

Christchurch, New Zealand

October 2017

A DECISION SUPPORT FRAMEWORK FOR SELECTING FEASIBLE COASTAL PROTECTION MEASURES IN THE REPUBLIC OF MALDIVES

By

ABDULLA THASLEEM ABDUL HAKEEM

Supervised by

Professor Rajesh Dhakal

and

Associate Professor Tom Cochrane

Department of Civil and Natural Resources Engineering,

University of Canterbury

Christchurch, New Zealand

October 2017

ABSTRACT

In the absence of effective coastal protection measures, low-lying countries face inevitable losses from coastal erosion and coastal flooding under future scenarios of sea level rise and climate change. The Republic of Maldives, the flattest and the lowest-lying country on earth, is one of the most vulnerable countries to the consequences of climate change. Any impacts to the coastline would directly impact the lives and livelihoods of the people, because of the proximity of settlements to the coastline and the dependence of the country's income on beach tourism. However, the increasing cost of these measures, resulting from evolving technical designs and increasing material prices, coupled with the politicized and ad-hoc nature of coastal protection decision making in the Republic of Maldives, has meant that coastal protection measures are inefficient and costly. Thus, there is a critical need for a method of systematic evaluation of protection measures to aid coastal protection decision making in the Republic of Maldives.

This research identified strategic information that would support the selection and implementation of appropriate coastal protection measures. Surveys of local stakeholders and professionals in the Republic of Maldives were used to identify the level of local stakeholders' knowledge and contribution in the decision making, professionals perception towards common coastal protection measures, and the key parameters and factors that could be used to evaluate the measures. Survey information, together with a thorough review of relevant decision support frameworks, policies, and coastal protection measures in the country and elsewhere, were used to device a coastal protection decision support framework, named THOSHI, for the Republic of Maldives.

This study found that coastal protection decision making in the Republic of Maldives needs a more systematic approach to reduce duplication, increase efficiency and enable the selection of appropriate measures for its varied island environments. Even though local stakeholders possess critical information useful for the decision-making process, currently there is minimal involvement of them in coastal protection decision making and the current institutional and policy framework for coastal protection in the country is inadequate, ineffective and weak. A survey of local stakeholders and industry professionals found that soft coastal protection options are not perceived to be viable solutions for the Republic of Maldives, if used exclusively. The survey also identified that the most important parameters for technical evaluation of coastal protection measures are technical viability, multi-hazard resiliency, and socio-aesthetic and environmental acceptability. The technical evaluation component of THOSHI was built on these parameters and used available cost data to design the financial evaluation component. The results of the case studies confirmed the applicability of THOSHI to different island environments and the ability of THOSHI to take into account unique stakeholder requirements and also conflicts between those requirements and technical considerations. For the problems identified in the case studies, the measures proposed through THOSHI were either identical or better solutions, both technically and financially, than the ones currently implemented.

It is expected that the application of THOSHI will facilitate decision makers in strategically evaluating and selecting feasible coastal protection measures for the Republic of Maldives, while also improving documentation, communication and collaboration with stakeholders.

Key words: coastal protection, shore protection, coastal engineering, ocean engineering, decision support framework, decision support systems, Maldives

ACKNOWLEDGEMENTS

In the Name of Allah, the Most Beneficent, the Most Merciful. All praises are due to Allah, to whom belongs all that is in the heavens and the earth, for He alone is truly Wise, All-Aware. I thank God for the countless blessings bestowed upon me and my family, and for giving me the strength and wisdom to complete this journey.

I extend my heartfelt gratitude to my primary supervisor Professor Rajesh Dhakal for his unwavering support, guidance and encouragement throughout the research period. This research would not have been possible if not for his fortitude in venturing beyond his usual research interests, his commitment to his word and patience especially through the testing initial months. I am also deeply thankful for having Associate Professor Tom Cochrane come on board as a secondary supervisor, and for his enthusiasm, guidance, constructive feedback and innovative ideas. His attention to detail and perseverance is deeply appreciated.

I am profoundly indebted to my business partners for their continuous support throughout my studies, especially my brother-in-law and friend, Ibrahim Shaheem. If not for his hard work and dedication to managing and expanding the business into more profitable ventures in my absence and dealing with various challenges on my behalf, I would not have been able to complete my studies as smoothly as I have. I also thank the staff of Lisa Maldives private limited for their support.

I am grateful to the Maldivian community in Christchurch, who have been my second family, for their encouragement and support extended to me and my family. The cheerful times spent with them have been a welcome distraction from the stresses of studies and their support during the birth of my daughter is beyond my ability to express. Their friendship made our stay in New Zealand an adventurous and an unforgettable one.

I am thankful to the island councils, professionals and local residents who participated in and supported my research. In particular, my warm gratitude goes to my friends and family who helped me with the research directly or through their networks.

I extend my sincere thanks and appreciation to Dr Ruqayya Sulaiman-Hill and the late Jennifer Horner for their assistance in proofreading and formatting this thesis.

I express my deepest appreciation to all the members of my family and my wife's family, especially my parents. Their love, encouragement and prayers greatly helped this dream come true.

I am deeply indebted to my wife Zimna Thaufeeg for her love, patience, and the tremendous support throughout this trying journey. Her help with every stage of my research from inception to completion, the enthusiasm she developed towards my research area and the various discussions on the subject which helped me dig deeper, think harder and work with more determination. I am truly grateful to her for taking care of and nurturing our son and gifting me with a beautiful daughter, which made the hardest final days of my research joyful. She is my inspiration and this endeavour would be impossible without her. I express my profound love and admiration to my children, Yusuf and Haajar, who are my emotional sustenance.

I dedicate this thesis to my beloved parents, my wife and children.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS AND ACRONYMS

AOSIS	Alliance of Small Island States
ASEAN	Association of South-East Asian Nations
ATC	Average Total Cost
BW	Breakwater
CanVis	A Tool for Visualising Coastal Changes and Potential Adaptation Strategies
CBA	Cost-Benefit Analysis
CCAC	Climate Change Advisory Council
CCD	Climate Change Department
CCORAL	Caribbean Climate Online Risk and Adaptation Tool
CCVI	Climate Change Vulnerability Index
COSALC	Coast and Beach Stability in the Caribbean
COSMO	Coastal zone Simulation Model
DCA	Danish Coastal Authority
DINAS-COAST	Dynamic and Interactive Assessment of National, Regional and Global Vulnerability of Coastal Zones to Climate Change and Sea-Level Rise
DIRAM	Detailed Island Risk Assessment in the Maldives
DIVA	Dynamic Interactive Vulnerability Assessment
DN	Do nothing
DSF	Decision Support Framework
DSS	Decision Support System
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency
EPPA	Environmental Protection and Preservation Act
ESA	Environmentally Sensitive Areas
EU	European Union
GDP	Gross Domestic Product
GIS	Geographic Information System
GNP	Gross National Product
GNS	Geological and Nuclear Sciences
GoM	Government of the Maldives
HAZUS-MH	Hazards United States - Multi-Hazards
HL	Hold the Line
HRCE	Hazard Risk of Coastal Erosion

HSO	Hard Structural Options
ICM	Integrated Coastal Management
ICZM	Integrated Coastal Zone Management
InVEST	Integrated Valuation of Environmental Services and Trade-offs
IPCC	Intergovernmental Panel on Climate Change
IPCC-AR5	The Fifth Assessment Report of the IPCC
ISDR	International Strategy for Disaster Reduction
LI	Limited Intervention
MCPI	Ministry of Construction and Public Infrastructure
MEE	Ministry of Environment and Energy
MEEW	Ministry of Environment Energy and Water
MHE	Ministry of Housing and Environment
MHI	Ministry of Housing and Infrastructure
MHRE	Multi-Hazard Resiliency
MHTE	Ministry of Housing, Transport and the Environment
MLW	Mean Low Water
MoFT	Ministry of Finance and Treasury
MR	Managed Realignment
MS	Move Seaward
MSL	Mean Sea Level
MTCC	Maldives Transport and Contracting Company plc
MVR	Maldivian Rufiyaa (US$1 is equivalent to MVR15.42)
NAPA	National Adaptation Program of Action
NCO	Novel or Combined Options
NEAP	National Environmental Action Plan
NEM	North East Monsoon - *Iruvai'* (dry period - from January to March)
NGO	Non-Governmental Organisations
NOAA	National Oceanic and Atmospheric Administration
NPC	National Planning Council
NSO	Non-Structural Options
OpenNSPECT	Open-source Nonpoint Source Pollution & Erosion Comparison Tool
PAD	Preliminary Assessment Document
PDC	Population and Development Consolidation
Recl	Reclamation

RISC	Risk Information System Coast
RoM	Republic of Maldives
Rvt	Revetment
SE	Socio-aesthetic and Environmental acceptability
SIDS	Small Island Developing States
SimCoast	Numerical Simulation Tool for Protection of Coasts against Flooding and Erosion
SIP	Safer Islands Program
SLAMM	Sea Level Affecting Marshes Model
SLR	Sea-Level Rise
SLRCFIV	Sea Level Rise and Coastal Flooding Impact Viewer
SMP	Shoreline Management Plan
SNAP	Strategic National Action Plan
SNC	Second National Communication of the Maldives
SoE	State of the Environment
SoVI	Social Vulnerability Index
SSO	Soft Structural Options
SW	Seawall
SWM	South West Monsoon - *Hulhangu*' (rainy period - from May to November)
TC	Total Cost
TSHD	Trailing Suction Hopper Dredgers
TV	Technical Viability
UC	University of Canterbury
Udha	Tidal swells
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
USACE	United States Army Corps of Engineers

1 INTRODUCTION

1.1 OVERVIEW

Thermal expansion of seawater due to global warming and increased water mass input resulting from melting of ice are causing global sea levels to rise (Nicholls & Cazenave, 2010). The Intergovernmental Panel on Climate Change (IPCC) have projected in their fifth assessment report (IPCC-AR5) that global sea level rise (SLR) will accelerate through the next century and beyond and the impacts will become more apparent, especially in the Small Island Developing States (SIDS)(Edenhofer et al., 2014). Nicholls and Cazenave (2010) also agreed that SIDS will experience the largest relative increase in impacts, and stated island nations such as the 'Republic of Maldives (RoM) will face the real prospect of submergence and complete abandonment during the 21st century'.

The RoM is a chain of 1,192 low-lying islands in 26 naturally formed atolls administratively grouped into 20 atolls (Figure 1-1) in the Indian ocean and with a population of 407,660 (NBS, 2014). The 300 km² of land area stretches over 820 km from latitude 7°6'35"N, crossing the Equator to 0°42'24"S, and lying between 7°032'19"E and 73°46'13"E longitude. With an average ground level of 1.5m above sea level, the RoM is the planet's lowest-lying country (USAID, 2012). Coastal erosion is prevalent on a large number of islands across the RoM, and the Indian Ocean tsunami of 26th December 2004 (tsunami 2004) has exacerbated coastal erosion in many islands (Kench, 2010; MEE, 2011). Coastal flooding and sea swell incidents have also increased in the last couple of decades (MEE, 2014). The low-lying nature of the islands, combined with their geographic dispersion, fragile environment, remoteness, vulnerability to natural disasters, and limited economic capability, further exacerbate the country's vulnerability to coastal erosion and other related climate change issues (MEE, 2015).

Given its vulnerability to SLR, the RoM has been at the forefront of climate change coverage since the late 1980s (Henson, 2006). It is notably, the first country to sign the Kyoto Protocol and is also a party to the United Nations Framework Convention on Climate Change (UNFCCC) (MEE, 2011). The RoM also joined forces with a few other SIDS in 1990, to establish the Alliance of Small Island States (AOSIS) to advocate for climate action at the United Nations (UN). The RoM is currently (2015-2017) the Chair of AOSIS (MEE, 2015). Furthermore, the RoM convened the SIDS Conference on Sea Level Rise in 1989, to seek global attention for the plight of vulnerable SIDS. In addition, the country has demonstrated strong political commitment and 'climate leadership' at the highest levels of the government. For example, in 2009, President Mohamed Nasheed and his Ministers held an underwater Cabinet meeting, and signed a document calling for global cuts in carbon emissions, to highlight the threat of global warming to the RoM (MEE, 2015).

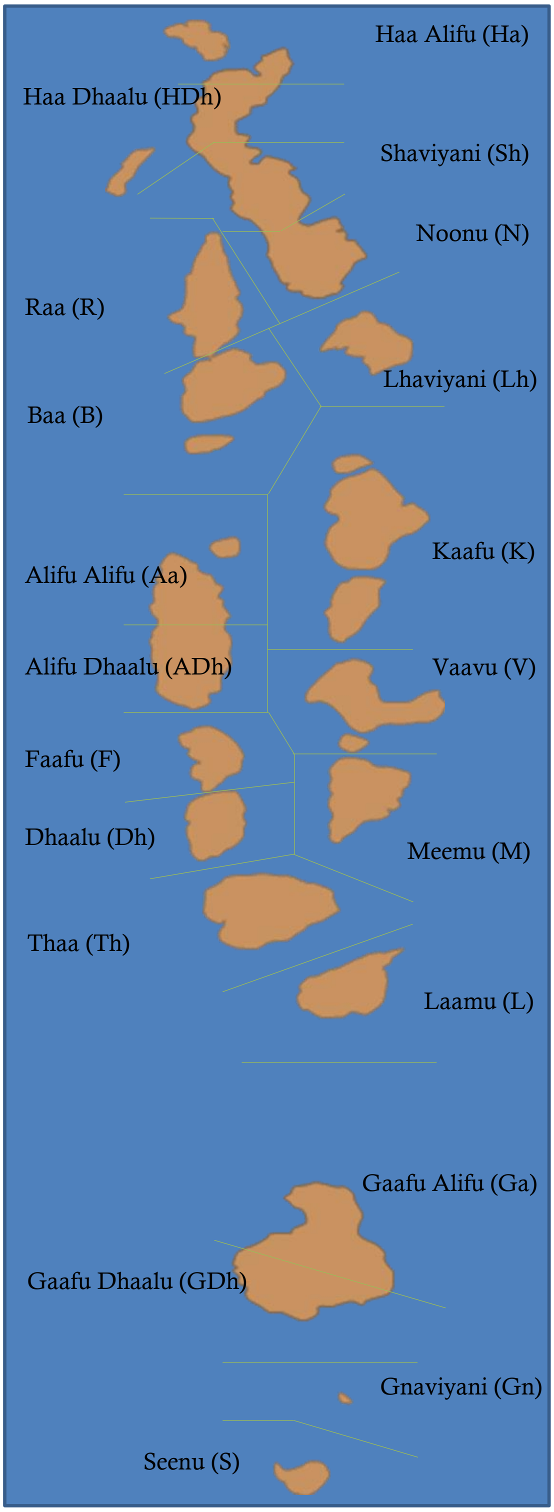


Figure 1-1 Map of the RoM showing the administrative divisions.

Despite various challenges posed by the limited financial and human capacity, the RoM demonstrated the country's determination in adapting to the adverse impacts of coastal erosion and other climate change related hazards (MEE, 2014). Over the past few decades, significant actions have been undertaken to increase the country's resiliency to coastal erosion and other climate change related hazards (MEE, 2015).

Even though numerous efforts according to MEE (2015) are being made to implement measures resilient to the impacts of coastal erosion, SLR and other related hazards, poor decision making in the selection of effective coastal protection measures could make their functioning impractical for their intended purposes (Kench, 2010). Dean and Dalrymple (2004) recognized that the technical, economic and social aspects of coastal protection measures are important information that could be used to systematically evaluate different coastal protection measures.

1.2 STATEMENT OF PROBLEM

Small changes in sea level can have significant consequences in low lying coastal areas. The combination of predicted SLR, tropical storms and cyclones will further increase the vulnerabilities with respect to design waves and surge levels (Nicholls et al., 2007b). Coastal areas could be inundated so often or eroded so severely that inhabitants will be forced to abandon their homes and businesses (ERG, 2013; NOAA, 2013; OECD, 1991). As the nature of coastal responses to these changes has become an issue of urgency, the need for designing coastal protection measures that can survive a significant range of design conditions, with limited damage in these extreme situations, are urgently required (Forbes et al., 2004; J.S. Reedijk et al., 2009).

Although some countries are fiscally and technologically self-sufficient to endure the consequences of SLR and safeguard lives and livelihoods of their coastal communities, most of the low-lying SIDS have no resources to face the consequences independently (Chen & Zong, 1999). Additionally, because of the geographical dispersion of the islands, the extent of coastlines around each island, and the lower economic status of the country, the issue of coastal protection for the RoM stands out clearly from all other countries. Thus, the need to select efficient and cost-effective coastal protection measures is crucial for the survival of the country.

A large percent of populations in low-lying countries are engaged in fisheries, tourism, and related activities and live very close to coastlines (Vermaat & Thampanya, 2006). In the RoM, a large percent of the settlement footprints of all inhabited islands and the country's entire resort infrastructure are within 100m of the coast. Severe erosion and coastal flooding would thus impact adversely on the economy as well as potentially posing a serious threat to lives and livelihoods of the communities. In addition, the lack of higher grounds within the islands, and the increased frequency and intensity of coastal erosion, flooding, and inundation could make the islands uninhabitable (MEE, 2015). Therefore, appropriate adaptation and coastal protection measures are urgently needed to defend the Maldives' human settlement. Coastal protection concerns for the RoM identified in three key areas (coastal zone management, critical infrastructure, and tourism) that are linked to the vulnerabilities to climate change and sea-level rise are presented in Table 1-1.

Table 1-1 Climate change and sea level rise vulnerabilities of the RoM, adapted from MEE (2015)

Coastal zone Management: • 80% or more of the total land area is less than 1m above Mean Sea Level (MSL) • About 44% of the settlement footprints of all islands are within 100 m of the coastline • 50% or more of the residential housing in 121 islands are within 100 m of the coastline • 'More than 97% of inhabited islands reported beach erosion in 2004, of which 64% reported severe beach erosion' (MEEW, 2006). However, about 67% of inhabited islands reported beach erosion in 2013 at different scales and of different severity • Because of human intervention in coastal areas, severity and the patterns of coastal erosion have been further complicated. The adaptation measures to mitigate erosion in the islands, due to its lack of planning and poor design, have led to increased maladaptation countrywide
Critical Infrastructure: • The infrastructure of all the four international airports in the RoM is within 50m of the coastline. • 90% or more of all resort infrastructure and almost all of the tourist accommodations are within 100 m of the coastline. • Approximately 70% of all fisheries infrastructure is within 100 m of the coastline. • Utility facilities including most powerhouses and waste facilities are located within 100m of the coastline. • 75% or more of all communication infrastructures are within 100 m of the coastline.
Tourism: • Nearly 45% of the resort islands have reported varying degree of coastal erosion. • Rise in temperature leads to coral bleaching, loss of beach and vegetation, and salt intrusion. • Maldivian tourism product is based on sea, sand and sun. Adverse impacts on climate variability will have negative consequences to the tourism industry.

In the absence of coastal protection measures, the high-end SLR scenarios combined with climate change risks are likely to make some islands and low-lying areas unviable by 2100 (Nicholls et al., 2007c). Case studies conducted on 22 countries and 8 local areas with a meter rise in sea level in 100 years under a 'do nothing' scenario, estimated a loss of assets worth over MVR16,962 billion, an affected population of nearly 180 million, and land loss of over 150,000 km², including 62,000 km² of coastal wetlands (Etemad-Shahidi & Bonakdar, 2009; Nicholls & Misdorp, 1993). SIDS stand out as being particularly vulnerable from most perspectives and thus effective coastal protection is urgently required.

To safeguard the lives and livelihoods of Maldivian communities from coastal erosion and other climate vulnerabilities that are concerns for coastal protection, the Government of the RoM have proposed to UNFCCC, MVR 6,163 million for various adaptation activities in 2010 (Table 1-2), the majority being coastal protection and related works (MHE, 2010).

Table 1-2 Adaptation priorities proposed for UNFCCC funding in 2010 (Adapted from (MHE, 2010))

Proposed area for funding	Amount in million MVR
Coastal protection of 4 islands	233
Coastal protection works in other selected islands	1,188
Flood control measures for vulnerable islands	86
Integration of communities AND Integrating Climate Scenarios into Safer/Resilient Islands Strategy, and Planning	1,843
Coastal protection of Malé International Airport	302
Coral reef protection throughout the country	21
Development of 9 islands into Safer/Resilient islands	2,490

Although the country receives various grant aids and international assistance for coastal protection, the decision makers are not equipped with the right tools, systems or frameworks they need to make sound decisions in selecting the most appropriate or feasible coastal protection measures (EPA, 2014; MTCC, 2014). The unavailability of appropriate coastal protection strategy evaluation and selection tools has created delays and difficulties in project initiation, implementation and maintenance (Swan River Trust, 2009). To fill this gap, in some countries, 'decision makers use knowledge-based systems through networks of people, ideas, and information' (Kouwen et al., 2008). However, in the RoM, *ad hoc* strategies, based on the knowledge of small groups of decision makers equipped with international standards such as coastal engineering manual and shore protection manual by USACE, are currently used in the coastal protection decision making (MEE, 2014). Furthermore, some of the coastal protection measures are selected merely on the cost-benefit studies conducted on a handful of locally available techniques (Venton et al., 2009).

Deciding on the best course of action is not always easy, and issues related to coastal protection are complex (NOAA, 2013). There are currently no tools or frameworks addressing the systematic evaluation and selection methodology for feasible coastal protection measures that countries like the RoM could use or adapt. Most of the tools currently available are policy-evaluation tools on integrated coastal zone management (ICZM). Despite the lack of availability of decision support frameworks (DSF), the government of the RoM firmly believes strategic assessment and evaluation of various coastal protection measures are of enormous importance to the country (MEE, 2015).

This emphasises the importance and urgency of the design and development of a systematic framework for coastal protection decision making in the country. Application of coastal protection DSF is anticipated to bring numerous benefits, such as increasing transparency of the evaluation process, cost savings, identifying resilient structures for different scenarios, and providing opportunities to improve efficiency of the decisions made.

1.3 Aim and Objectives

The aim of this research is to devise a coastal protection DSF to facilitate coastal protection decision makers in evaluating different coastal protection measures in the RoM. Selection of the measures will be based on their technical viability, multi-hazard resiliency, socio-aesthetics and environmental acceptability, and financial feasibility.

The specific research objectives include:

- To identify existing policies, regulations and documentation relevant to coastal protection decision making in the RoM and to identify gaps in policy or knowledge.
- To identify common coastal protection measures used in the RoM and document their advantages and limitations
- To understand stakeholders' awareness of and interaction with different coastal protection measures and decision-making processes, and understand impacts to the current process of coastal protection decision making in the RoM, if the level of stakeholder contribution is increased in the formulation of strategies and decision making for coastal protection works

- To understand professionals' perception and attitude towards the common coastal protection measures used in the RoM and to identify the parameters and factors important for coastal protection decision making
- To conceptualise and design a coastal protection DSF for the RoM
- Apply the DSF to selected case studies.

The following section summarises the methodological and theoretical perspectives adopted for this research. The details of the methods used for data collection and analysis are discussed in each respective chapter.

1.4 Research Methodology Overview

Two interpretive approaches, Phenomenology and Grounded Theory (GT) were explored and compared, to identify which methodology was provided the most useful tools to achieve the goals of research study.

Phenomenology is used to better understand a social phenomenon through a richer analysis of the lived experiences, while Grounded Theory aims to "develop an explanatory theory of basic social processes" (Starks & Brown Trinidad, 2007). Starks notes that although some similarities exist in the interview strategies and analytical methods used for dealing with the data, the types of samples drawn are different. Phenomenology was found to be applicable to a single area of study under non-varying conditions while GT can be applied on an area of interest under different conditions (Starks & Brown Trinidad, 2007). Thus, GT utilises a representation of the conditions to draw its samples.

The utilization of a variety of sources of data grounded in particular contexts, and the capability of generating 'theory from the range of experiences' (Holloway, 1997) (Corbin, 1990) gives GT the deductive capability to probe around and explore further (Starks & Brown Trinidad, 2007). Hence, in GT, as one collects and analyses data, any gaps that are discovered or patterns that need more explanation are catered for through more data collection and analysis or re-examination of previously obtained data. In this way, GT can refine a theory using as much data as needed to make it grounded.

Grounded Theory was adopted for this research since it was important to understand the coastal processes in RoM, in its varied island contexts so that the resulting decision making framework would be more encompassing and inclusive. The adoption of GT for this research allowed the researcher to understand the difference in perception or 'slices of data' more clearly (Strauss & Corbin, 1994). The different parameters that affected coastal protection decision making in the RoM and their relative importance were identified through interviews and focus group discussions. And in GT, researchers typically find gaps in the initial stage, establish logical objectives or ways to fill the gap, seek strategic ways of gathering specific additional data to develop the emerging theory. (Charmaz, 2007). As such, during the data analysis, as some factors became more apparent, these factors could be further tested for applicability in different contexts by going back to data. Thus, utilising GT enabled the process of theorising from data, and using more data to further refine and inform the theory. Turner (1981) noted that grounded theory would be more suitable to deal with qualitative data from participant observation, face-to-face interactions, semi-structured or unstructured interview, and case-study material or other kinds of documentary sources. And since this research also used qualitative interpretive approach of data collection from stakeholder groups, GT emerged as the more suitable methodology to this research.

The inductive nature of GT also allowed the flexibility to use various types of data collection methods, and the ability to identify research position without requiring hypothesis testing (Glaser & Strauss, 1967). From the different aspects of GT described by Martin and Turner (1986), this research utilised literature review and qualitative interpretive approaches of data collection such as semi-structured interviews, surveys, and focus group discussions. GT also played a key role in guiding data collection throughout the research, informing concept definitions and utilising grounded analysis of the literature to facilitate conceptualization of the DSF.

An initial literature review was completed to identify the research gap – unavailability of coastal protection DSFs or tools to systematically evaluate coastal protection measures in the RoM. Perception surveys, semi-structured interviews were conducted to obtain the perceptions of local stakeholders (stakeholders from local communities and professionals), and where the surveys pointed to a pattern or irregularity, focus group discussions helped to gain a better understanding of those patterns or irregularities.

The processes involved in the research are summarized below.

1. Initial literature review

The research began with reviewing literature to:

(a) Identify background information of the RoM,
(b) Identify the state of the problem, and
(c) Recognize the need and importance of a coastal protection DSF.

2. **Establishing the aim and objectives of this research**

   Based on the important observations of the initial literature review that identified the state of the problem and the need and importance of a coastal protection DSF, the research aim and objectives were established.

3. **Compilation of a comprehensive literature review on focused areas**

   When the theoretical framework of the research was conceptualized based on the aim and objectives, the research then focused on elaborating the key areas under study. A further literature search was then undertaken to explore different types of coastal protection measures, and to identify the policy of the RoM towards coastal protection works.

4. **Data collection**

   Following the literature review, strategies for collecting, analysing, and presenting the perspectives of different stakeholders for the study were devised.

   Ten inhabited islands across the RoM that are targeted development centres in terms of infrastructure development and strategic population consolidation were selected to collect data through surveys, interviews and focus group discussions. Questionnaires, focus groups discussions, and interviews were conducted to collect data from stakeholder groups.

   A public opinion survey using qualitative questionnaires was used to collect data from residents of the participating islands. The questionnaire aimed to identify the community's current contribution in the coastal protection decision making, to recognize the key local stakeholders, and to identify the desired protection measures for the community. Other aspects of stakeholder knowledge such as what they value about coastal protection measures; what factors impact their island coastlines, what guiding principles they feel should be incorporated into decision making, implementation, and maintenance of coastal protection works, were also included in the broader objectives of the survey. Initially, a postal questionnaire was intended to be used due to the expensive nature of field visits to remote islands. However, the drawbacks of postal surveys such as the slow speed of rural post, inability to provide clarifications for technical contents and confusions that arise while questionnaires are in the field and low response rates ruled out using a postal questionnaire (Champion & Sear, 1968).

Focus group discussions were also conducted in all the ten islands to identify local knowledge regarding coastal protection measures implemented, understand their impacts through key informants, and obtain other information that could be used in the case study implementation part of the research. Focus groups are where a small number of stakeholders meet with a facilitator to discuss specific issues and are a useful method to collect qualitative data (Williams & Katz, 2001). A small group of participants from each island contributed in the focus group discussions. The participants include members of the local council, atoll council, island administrative officers (previously known as *Katheebs*, and previously in charge of governing the islands) and key members of local NGOs and elderly residents who have contributed in the coastal protection decision making in some form. Elderly residents were particularly targeted, as most are well-informed and knowledgeable with regard to local coastal protection in the RoM (UNDP (2007).

Like the public opinion survey, the initial plan was to collect professionals' perception through a survey questionnaire. However, after expert opinion from a group of professionals from the Maldives Transport and Contracting Company plc (MTCC), it was changed to semi-structured interviews as numerous advantages were emphasized. Some of the advantages of semi-structured interviewing include the researchers' active engagement with the professionals to explore tacit knowledge that would otherwise have not been realized through a survey questionnaire (Babbie, 2004), as well as the freedom it gives to probe the professionals to elaborate on an original response or to follow a line of inquiry introduced by the researcher (Hancock et al., 2007). Additionally, the semi-structured interpretive approach recognizes different viewpoints that are subjective in nature (Jennings, 2005). Mason (2002) recognized interviewing as the most common method of qualitative data collection and identified that in-depth, semi-structured, and loosely structured are the three types of interviewing.

In addition to the primary data collected from stakeholder groups, data from the multi-hazard assessments conducted on the same set of islands by UNDP (2007) UNDP (2006) were recognised as an integral part of the DSF developed through this research as it is the only available data set that extensively covered multi-hazards for the selected islands. However, data on the hazards were further refined or supplemented, as required, by information and data from the literature review and the research conducted.

5. **Conceptualizing Coastal Protection Decision Support Framework, THOSHI**

The literature reviews and the data collected through the semi-structured interviews, survey questionnaires, and focus group discussions informed the development of the Coastal Protection DSF, 'THOSHI'. THOSHI is a common terminology used in the RoM for coastal protection measures, especially, hard protection options. For instance, breakwaters and seawalls are referred *Beyru thoshi* and *Eggamu thoshi* respectively. As the DSF developed is intended particularly for the RoM audience, it seemed appropriate to the name the DSF, THOSHI.

The qualitative data collection through surveys and questionnaires together with further literature search helped to conceptualize the structure of THOSHI. The important aspects considered while conceptualizing THOSHI include:

- formulating a flexible DSF that includes windows for enhancement and improvement in future,
- capability to convert it into a computer based software if need arises so it will be easy to use, and
- allows a range of options for the decision makers to compare as per their preference.

6. **Application of THOSHI to case studies**

Two different case studies were implemented for Haa Dhaalu Kulhudhuffushi and Gaafu Dhaalu Thinadhoo using THOSHI, to check the applicability of the framework. The case studies utilized the step-by-step procedure of THOSHI and compared the results generated by THOSHI to the current decisions implemented in the case study islands.

1.5 Structure of the Thesis

This thesis is structured as follows:

Chapter 1 introduces general background of the study and identifies the problem and the need for the research. It also sets the aim, objectives, and the overall methodology of the research.

Chapter 2 provides a comprehensive literature review on various coastal protection measures and decision support tools/systems/frameworks. Various approaches of coastal protection, their advantages and disadvantages are presented.

Additionally, different types of DSFs relevant to coastal protection and their advantages and disadvantages are summarized.

Chapter 3 discusses the common coastal protection measures in the RoM, highlighting their advantages and disadvantages in the RoM context. The chapter also identifies different parameters and factors such as technical viability, multi-hazard resiliency, and socio-aesthetics and environmental acceptability of the measures.

Chapter 4 presents the policy of the RoM towards coastal protection works. It highlights the institutional set up, and analyses the existing policies and regulatory frameworks relevant to coastal protection works in the country. Additionally, it analyses other relevant documents and programs supporting coastal protection works in the RoM, and finally summarizes policies and regulatory instruments elsewhere supporting coastal protection.

Chapter 5 presents surveys conducted in ten inhabited islands in the RoM to understand local stakeholder's (residents of surveyed islands) contribution and awareness towards coastal protection works in the islands. It analyses and discusses the surveyed data from stakeholder perceptions and awareness of coastal protection works in the RoM. The broader areas targeted in the survey include (1) demographic characteristics of surveyed islands, (2) management and protection of coasts: roles and responsibilities of different stakeholders, (3) public knowledge on different coastal protection systems, (4) valued attributes of coasts to public, (5) coastal hazards and risks, and (6) stakeholder contribution in the decision making. The main objective of the chapter was to identify whether the participants understand coastal processes and have the basic knowledge of common coastal protection measures used in the RoM to affectively contribute in the coastal protection decision making.

Chapter 6 presents the results of a series of interviews conducted to obtain professionals' perceptions on areas important for coastal protection works in the RoM. The broader areas covered include (1) the use and application of DSF, (2) planning and management approaches, (3) common coastal protection measures in the RoM, (4) technical viability, multi-hazard resiliency, and socio-aesthetic and environmental acceptability features of different coastal protection measures. The main objective of the chapter is to identify current ways of tackling the problems, understand professional perspectives on areas crucial for the development of a coastal protection DSF, and validate the key parameters and factors identified through the literature review to confirm their applicability to the DSF.

Chapter 7 presents the conceptual framework and describes the seven stages of THOSHI. The step-by-step approach used to identify relevant policies and to select feasible measures are also detailed out in this chapter. The parameters and factors used to evaluate coastal protection measures are described, along with the formulae used to calculate parameter weights. Additionally, the chapter presents a list of all the common coastal protection measures in the RoM with their average total cost per linear meter per year derived based on the financial cost calculations obtained from coastal contractors and published literature on the RoM.

Chapter 8 applies THOSHI in two different case studies in the RoM. It describes how the cases were selected, and provides island specific information of case study islands, identifies the problems, and then utilizes THOSHI to systematically evaluate different measures to solve the real-time issue(s). Finally, it discusses the outcomes of THOSHI implementation in relation to the specific problems and compares them with the real-time solutions already implemented.

Chapter 9 summarizes the key findings and conclusions of the research. It also identifies the limitations of the research and outlines recommendations for future work.

2 LITERATURE REVIEW

2.1 INTRODUCTION

The literature review is divided into two parts: coastal protection measures and Decision Support Frameworks (DSF). Firstly, the existing knowledge of the function and impacts of various coastal protection measures that are currently used world-wide, especially in low-lying countries, are reviewed and presented within two different groups: soft and hard coastal protection options. This information has been combined with the background information of the coastal protection measures available in the RoM. As an overall strategy, literature obtained from sources within the RoM is given priority. The literature is reviewed based on its relevance to the aim and objectives of the research.

Secondly, literature is reviewed with a focus on DSFs that are currently available to support decision making in a coastal protection problem similar to the RoM. Key features of each framework, together with their advantages and disadvantages, are then discussed. For the preliminary literature review, literature is first identified, evaluated and then analysed according to its contribution and relevance to the study area and the practicality of the research methodologies used.

Information and data on common types of coastal protection measures were reviewed to identify factors or parameters that could be used to formulate a coastal protection DSF for the RoM. Sources used for the literature review include: journal articles, conference proceedings, theses and dissertations, government reports, technical reports including analysis and assessments relevant to the focused area, books, and local newspaper articles.

2.2 COASTAL PROTECTION

Coastal protection is probably one of the most challenging areas in coastal management programmes due to the lack of scientific knowledge and data required to tackle the issues with appropriate solutions (Dias et al., 2003). The concept of coastal protection differs widely among ecologists and engineers. To ecologists, they are systems that enable coastal ecosystems to function in the most natural way. However, to engineers, they are structures that halt or mitigate coastal erosion and protect hinterland and nearby assets (Cooper & Mckenna, 2008).

In the past, coastal protection issues were treated as local problems in the RoM where islanders applied *ad hoc* protection measures using locally available resources (MEE, 2016). However, application of inappropriate coastal protection measures, in many cases, have extended and intensified erosion along other areas of the same coast and also nearby beaches (Dias et al., 2003).

Coupled with climate change and SLR, the issues of severe coastal erosion are on the rise. This escalation and the expensive nature of different coastal protection measures have changed the perception of many countries in the way they tackle coastal protection issues. As a result, the application of coastal protection measures have become more proactive, and the types of measures applied are generally more practical and fit for the purpose (Pilarczyk, 2003).

2.2.1 Coastal Protection Policies and Types of Measures

There are some commonly used policy options or approaches to deal with coastal protection problems: Fixing the coastline position, reducing the erosion rate, retreating, restoring the beach or moving it seaward, adaptation and/or accommodation and do nothing. Different studies have classified these policies in different ways with broad similarities. Table 2-1 shows how some of these classifications relate to each other.

Table 2-1 Classification of coastal protection policies

<table>
<tr><th>Gilbert and Vellinga (1990)</th><th>Pope (1997)</th><th>Eurosion (Salman et al., 2004))</th><th>USACE (2002)</th></tr>
<tr><td rowspan="2">Protection</td><td>Armouring</td><td rowspan="2">Hold the Line</td><td>Armouring</td></tr>
<tr><td>Moderation</td><td>Shoreline Stabilisation</td></tr>
<tr><td>Beach Nourishment</td><td rowspan="2">Restoration</td><td rowspan="2">Move Seaward</td><td rowspan="2">Beach Restoration</td></tr>
<tr><td>Retreat</td></tr>
<tr><td rowspan="2">Accommodation</td><td rowspan="2">Adaptation</td><td>Managed Realignment</td><td rowspan="2">Adaptation and Accommodation</td></tr>
<tr><td>Limited Intervention</td></tr>
<tr><td>Do Nothing</td><td>Abstention</td><td>Do Nothing</td><td>Do Nothing</td></tr>
<tr><td></td><td></td><td></td><td>Combinations of measures</td></tr>
</table>

While each classification has its merits in terms of the distinctions it makes, for this research, the Eurosion guide classification is used. The descriptions of the policies are detailed below.

Hold the Line (HL) encourages maintaining the existing coastline in position. If an existing measure is in place it has to be maintained or changed to more resilient type to hold the existing defence line. HL also allows additional hard measures to be erected in front (seaward) of the existing defence line.

Managed Realignment (MR) requires deliberate breaching of existing coastal protection with the adjacent land consequentially being flooded, and needs additional inland areas for the lives and livelihoods in that area to be relocated (Luisetti et al., 2011). This is because the existing measures are either too costly to maintain or less beneficial to the local community. A new line of defence could be installed landward to the original line of defence under this policy.

Move seaward (MS) is encouraged in areas where flooding, erosion and overtopping hinder the use of infrastructure and other inland amenities. Also, to cater for the growing population and development demands in potential islands MS is a common approach to increase land area in the RoM. New lines of defence are generally required seaward of the new coastline under this policy.

Limited Intervention (LI) attempts to slow down the coastal process rather than forcing it to stop completely. Therefore, LI is generally not recommended to areas where wave action is strong.

Do nothing (DN) is a policy where any physical protection measures are discouraged, thus no investment in coastal defence assets or operation is require.

'The USACE Coastal Engineering Manual' USACE (2002) uses a slightly different classification that roughly matches the Eurosion guide; namely, Coastal Armouring structures, Shore Stabilization structures, Beach Nourishment, Adaptation and Retreat, Combination and New Technologies and Do Nothing. However, the main aim of the USACE classification is to classify protection measures rather than policies and thus focuses on the differences in the type of measure rather than aim of implementing a measure. And since this research makes a distinction between protection policies and measures, the Eurosion guide classification of policies is chosen to be used.

Most coastal protection measures fall into either Hard structural or Soft structural measures. McCue et al. (2012) categorises coastal protection measures under four categories, soft structural options, hard structural options, accomodation approaches (non-structural options), and no-active intervention (do nothing) options. Since Do Nothing is already included under policies, Do Nothing is discarded as a classification for protection measures. On the other hand, the USACE classification of combination and new approaches is included to accommodate more versatile solutions. As a result, for the purposes of this research, the classification of measures is revised into four categories: Hard Structural Options (HSO), Soft Structural Options (SSO), Non-Structural Options (NSO) and Novel and Combined Options (NCO). Most of the commonly used measures in the RoM can fit under this classification. Soft structural options are generally described as coastal adaptation measures that enhance the natural processes of the coastal environment (Kench, 2010). Hard structural options are mostly civil engineering measures designed to control the impacts of direct wave attacks (MEE, 2016; MHE, 2011b). Non-structural options are regulatory controls where no structural measures are applied (MEE, 2016; MHE, 2011b). Table 2-2 shows the classification and the types of different coastal protection options in the RoM with their primary purposes, applicable coastal processes, their impacts to the environment and their durability.

Table 2-2 Classification and the types of different coastal protection options in the RoM with their primary purposes, applicable coastal processes, their impacts to the environment and their durability. Reproduced and adapted from Beca (2010); Burkett and Davidson (2012); (McCue et al., 2012)

Measure / Classification	Type	Primary Purpose(s)	Applicable Coastal processes	Environmental Impacts	Design Life
Non-Structural Options	**Regulatory controls** - *Relocation of threatened buildings* - *Creation of buffers or set-back zones*	Move away from the hazard area (coastal erosion or floodable area) without the application of any physical measure. Provide sufficient land area (safer zone) between hinterland assets and hazard area.	Applicable to high, medium and low energy settings (where there is sufficient land area to relocate or create a buffer/set-back zone).	Requires suitable area to relocate hinterland assets which may involve environmental impacts depending on the site chosen. Some impacts may include: Deforestation, Taking over arable land, disruption and destruction to habitats.	Longevity of the control measure depends on the rate and severity of erosion and width of the buffer or set-back zone. Normally the life is short - it takes coastal erosion to reach the new sites if the relocated area is within close proximity of the coast.

Soft Structural Options	Reclamation, Nourishment	Replace the material lost. Create new lands or expand existing lands. Act as buffers - provide some degree of protection from erosion and flooding.	Recommended to medium or low energy settings. Not applicable to areas experiencing high sediment transport.	Balances the material lost due to erosion, flooding and storms. Create new habitats. Provide additional land areas.	Less durable. Indefinite if regularly maintained.
	Vegetation	Reduce the rate of erosion by slowing down the impact of wave energy by trapping materials. Provide some degree of protection from erosion.	Low energy setting. Have certain degree of control on wave height. Not suitable against flooding/overtopping.	Trap littoral sediments and stabilise the beach. Take some time to mature and establish. Creates habitat for vulnerable species.	Less durable in high energy conditions. Indefinite in very low energy settings.
Hard Structural Options	Seawalls/Bulkheads/Quay walls	Prevent hinterland assets from direct wave impacts. Control or limit further erosion and overtopping.	Applicable to all energy settings. Recommended for high energy environments.	Limit longshore sediment - beach interactions. Increase scour at toe depending on the type of material used.	Design life mostly governed by material type. E.g. Reinforced concrete and mass concrete blocks can last 50+ years.

			Low applicability in flooding areas.	Creates habitat for vulnerable species.	
	Revetments	Dissipate wave energy. Control or reduce the loss of land from erosion. Protect land from overtopping.	Medium to low energy setting. Low applicability in flooding areas.	Limit longshore, and on shore sediment - beach interactions. Creates habitat for vulnerable species. Help to stabilise coastlines.	Design life is governed by the type used. For e.g. Sandbags can last approximately 10 years, rock armour approximately 50+ years.
	Breakwaters	Absorb wave energy, reduce wave run-up and overtopping. Suitable for protection against: erosion, flooding and overtopping.	Applicable to all energy settings. Recommended for high energy environments.	Limit the sediment transfer alongshore and offshore. Reflect or absorb wave energy and increase scour at toe depending on the type of material used.	Design life is mostly governed by the type of material used. E.g. Rock armour and reinforced concrete lasts approximately 50+ years, Sand cement bags only last for about 10 years or less.
	Gabions	Absorb wave energy, reduce wave run-up and overtopping. Suitable for protection against:	Periodic high, medium or low energy settings.	Interrupt the movement of sediment transfer alongshore and help to stabilise upper beach and coastline.	Limited life – about 10 years

		erosion, flooding and overtopping.		Sometimes releases non-indigenous cobbles to the beach.	
	Groynes	Deposit the material eroded from coastline on alongside the structure on one side. Protect coastline from erosion.	Medium or low energy settings. Sediments can be accumulated on one side. It may stabilise upper beach and coastline	Limit sediment transport alongshore and onshore. Disrupt natural processes, cause down drift erosion and sediment loss, if not managed properly.	Depend on the type of material used. Rock armour – unlimited life. Sand cement bags – approximately 10 years or less. Burial may extend life.

The following section presents the different types of coastal protection measures identified through the literature review. The Soft Structural Options are discussed first, followed by Hard Structural Options.

2.2.2 Soft Structural Options.

Soft protection approaches are construction techniques that try to improve 'the natural features as an option for adaptation' (MHE, 2011b). Soft coastal protection measures attempt to dissipate wave energy using natural coastal processes. In this way, soft measures work together with natural processes of sediment erosion, transport and storage, thus making soft protection measures low maintenance, yet able to respond to forces such as storms and SLR (Cooper & Mckenna, 2008).

Some of the soft protection measures have been identified to coastal managers as more desirable since the results appear more natural, are generally considered less expensive and are more effective over a longer period (Basco, 1998; Basco, 2001; Bijker, 1989; Koster & Hillen, 1995). There is also a growing interest in soft coastal protection measures in some countries, 'particularly as the capital cost of hard approaches and their maintenance continues to rise'(Basco, 1998).

There are many examples of replacement or modification of hard coastal protection measures with softer ones such as beach nourishments or dune management. In the last decade, more soft coastal protections were adopted in Italy as the authorities identified that their beaches protected with hard measures were modifying the coastal landscape, creating down-drift erosion, preventing a full recreational use of the beach, thus resulting in high maintenance costs(ADB, 2010). Because of the lower cost and easier implementation, soft coastal protection measures can be a good alternative for developing countries. However, the transition from harder to softer coastal protection is not an easy task, and hence requires heavy investments to understand the processes and develop appropriate solutions (Pilarczyk, 2003).

The need for continuous monitoring and restoration programs, and the limited application to only low energy conditions are considered disadvantages of soft approaches (Dias et al., 2003). 'The cost-benefit study of disaster risk mitigation measures in three islands in the RoM' recommended that a significant shift in attitudes towards softer protections measures in the RoM is required, considering the 'significant amount of uncertainty associated with hazard occurrence and intensity' (Venton et al., 2009).

Land reclamation

Land reclamation (reclamation) has mostly been used in the RoM as an option to reduce land shortage in the populous islands and is generally combined with hard coastal protection measures to alleviate coastal erosion problems (MHE, 2011b). This technique involves creating new land, generally from the sea. In areas where wave actions are low throughout the year, it is encouraged to use reclamation as a method of coastal protection (EPA, 2014). Additionally, reclamation projects provide natural permeable protection, and are less expensive than alternative types of coastal protection if the annual replenishment requirements are not too high (Thorn & Roberts, 1981b).

Reclamation dissipates wave energy in the same way they are dissipated in a natural sandy beach (Burkett & Davidson, 2012). When maintained to adequate dimensions, reclamation affords protection for the adjoining backshore. However, beach nourishment is required to ensure the replenishment rate is attained (USACE, 1984).

Some form of reclamation is present in most of the inhabited islands in RoM, usually associated with access harbour and channel dredging projects (MHE, 2011b). In some islands, the landscape has entirely changed due to significant reclamation (Kench, 2010). 'Reclamation can only be considered a protection measure when the new reclamation projects consider raising the island to prevent coastal flooding; however, reclamation projects are almost guaranteed to result in short-term severe erosion unless hard coastal protection measures are utilised' (MHE, 2011b). UNDP (2007) identified a number of issues in the current design and implementation methods of land reclamation in the RoM, 'which also has repercussions on the hazard exposure of islands' (MHE, 2011b), thus cannot be used independently as a coastal protection measure.

Beach nourishment

Nourishment (beach nourishment), sometimes called 'beach feeding' or 'replenishment', is one of the most common quick-fix coastal protection measures in the RoM, particularly in resort islands (MHE, 2011b). It is the process of adding beach fill material by other means (e.g. sand mining), to compensate for erosion or loss of beach. Nourishment involves the transport of material from sediment deposition area to the replenishment area. Nourishment is widely considered an environmentally benign strategy (Kench, 2010), and has been applied at many sites around the world including Australia, Asia, Europe and the Americas (Cummings et al., 2012).

Beach nourishment projects in inhabited islands are not overly concerned with the quality of the replenished beach since the primary purpose is to refill eroded areas and to have a sufficient buffer between the existing coastline and the hinterland (MHE, 2011b). In areas of high wave actions, nourishment schemes are generally a repetitive process to maintain a beach in its original position. After placing material on the coastline, the material ultimately spreads over the active profile of the beach by longshore movements (Stive et al., 1991). It is interesting to note that 20 to 25 percent of the nourished beaches around the world have remained stable in the past few decades (Bird, 1985).

The application of beach nourishment, to compensate for the loss of beach material due to severe erosion, requires the consideration of additional time and space for pre-planning and stock piling respectively (Stive et al., 1991). Nourishment in a low energy setting effectively balances the material lost by SLR and erosion (Bird, 1985; Gornitz et al., 2001; Raudkivi & Dette, 2002; Stive et al., 1991 ; van de Graaff et al., 1991). In most cases, repetitive nourishment is required to maintain coastline in position or to create a wider beach.

Vegetation

Coastal protection using vegetation is not a very common method of coastal protection, thus, has been idetified as a workable method of protection for very low energy areas (MEE, 2014). Vegetation is a very low cost measure that is easy to maintain (BOP, 2002). In low energy conditions, they dissipate wave energy, trap littoral drifts and sediments, and help to grow coastlines (Beca, 2010). However, because of the general wave conditions of the islands in the RoM, they are not suitable as a protection meausure by itself, thus can only be used in most cases as a combination option with structural options (USACE, 1981b). Some of the varieties of vegetation seen in the coasts of the RoM include Sea Lettuce, Sea Hibiscus, Beach Gardenia, Pandanus/Screw Pine, Tree Heliotrope, Sea Trumpet, Ironwood, Banyan Tree, Indian Almond, Portia Tree, Lantern Tree, Alexandrian Laurel, Nicker nut, and Poison Bulb (Sujanapal & Sankaran, 2016).

Danielsen et al. (2005) identified through analytical models that vegetation is very effective to reduce tsunami flow pressure. Additionally, vegetations have been identified as an efficient mitigate measure against storms (Salman et al., 2004). Other advantages of vegetation include creating habitats for vulnerable species, their capacity to in controlling littoral sediment flow (Beca, 2010), and the beauty they bring to the coastline where they are implemented (USACE, 1981b).

2.2.3 Hard Structural Options

Hard coastal protection measures are generally described as 'traditional civil engineering works that are designed to abate the impacts of natural forces' (MHE, 2011b). These strategies are used to control coastal erosion, stabilise the shoreline, and limit the amount of sand being transported by longshore movement by using hard engineering measures (Bacchiocchi & Airoldi, 2003; McCue et al., 2012). They involve the construction of hard structure within the inter-tidal zone to reduce wave energy and to stop the sea - hinterland interactions. Hard structures tend to fix the coastline in position and allow no flexibility in response to strong wave actions (Burkett & Davidson, 2012). Additionally, hard measures are used to provide a calmer area for mooring vessels, and reduce flooding of low-lying areas by wave over-topping (Thorne et al., 1995).

Hard coastal protection measures are widely used and have been the most common approaches to coastal protection in low lying countries (Bacchiocchi & Airoldi 2003). However, drawbacks in hard measures, such as inducing down drift erosion, and increasing beach reflectivity have been identified (Dias et al., 2003).

MHE (2011b) grouped hard coastal protection measures into two classes: armouring and shore stabilisation measures. Armouring measures 'guarantee no further retreat of existing beach line and wave overtopping', while shore stabilisation measures 'modify the coastal processes to achieve shore stabilization' (MHE, 2011b).

The most frequent construction of hard measures includes seawalls, breakwaters, groynes and gabions. These structures are considered durable and the actual service lives of these structures may often exceed one hundred years (Burkett & Davidson, 2012). Hard measures such as seawalls and bulkheads are common forms of coastal protection in urban areas that often intercept wave energy, increasing erosion at their bases, hence eventually undermining them (Hayen, 2006). Capital cost of hard coastal protection measures is generally high, requires constant maintenance, and adversely affects beach aesthetics (Dias et al., 2003).

When designing hard measures, especially for seawalls and breakwaters, wall heights are raised to accommodate wave attack and SLR. However, many existing measures do not have sufficient foundations to support any further increase in height (Boorman et al., 1998; Sorensen, 1991). This means that as SLR occurs or wave actions become stronger, many of the older measures will not be able to be modified and thus reduce their life span. As a result, these older measures with insufficient foundations become less effective as coastal protection measures (Thorn & Roberts, 1981a)

Many occurrences of destructive coastal erosions are identified as the results from the construction of inappropriate hard protection measures (Komar, 1983). In most cases, these side-effects of inappropriate measures are undesired and additional funds and other resources such as expertise from coastal engineers are required to cope with them (Bacchiocchi & Airoldi, 2003).

Revetments

Revetments are shore parallel structures with the principal functions of reducing wave erosion of the coastline, reducing flooding of low-lying areas, and producing calmer water in harbour areas (Kench, 2010; Thorne et al., 1995). They 'typically consist of a cladding of stone, concrete, or asphalt to armour sloping natural shoreline profiles' (Ahrens, 1989; CIRIA, 2007; Dean & Dalrymple, 2004; SPM, 1984). The protective material laid on slopes dissipates wave energy with less damaging effects on the beach than waves striking vertical walls (USACE, 1984).

Revetments are suitable to use in high energy environments to absorb wave energy and mitigate severe erosion. They are identified as an effective coastal protection measure in the RoM (MHE, 2011b).

In severe storm conditions, loose rock formation will be disrupted unless mechanically fastened or heavier armour stones are used. An important design parameter used in the Hudson formula for placed block revetment is the thickness of the blocks (Payne, 1980). Constructing a well-designed revetment will significantly reduce storm surges. The determination of the depth of the toe of the construction especially needs special attention in order to prevent its failure due to scouring in front of the structure (van de Graaff et al., 1991). Figures 2-1, and 2-2, show the typical cross sections of revetments.

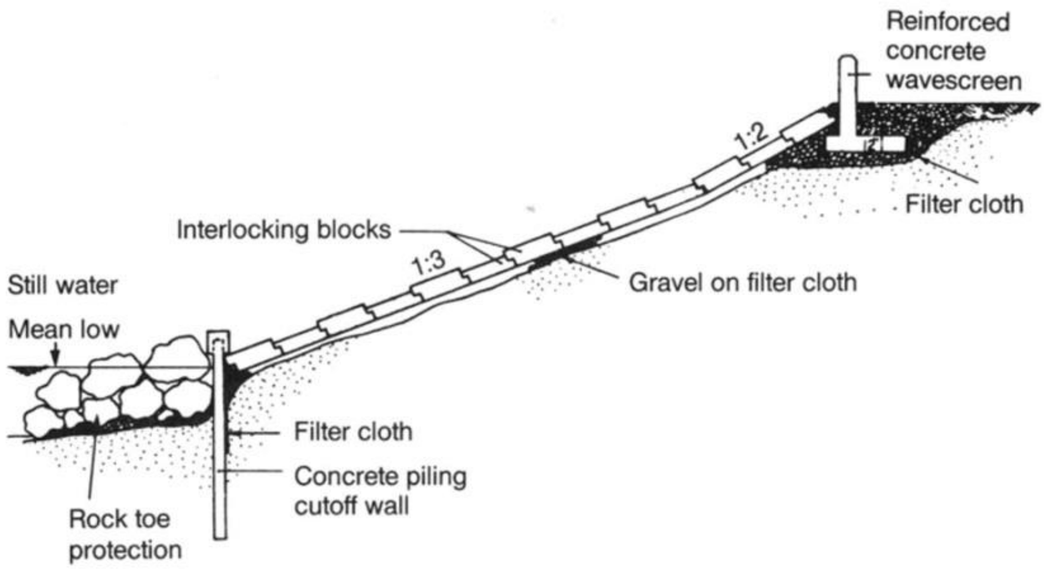


Figure 2-1 Interlocking concrete block revetments are suitable for low to moderate wave climate. Reproduced from O'Neill Jr (2000).

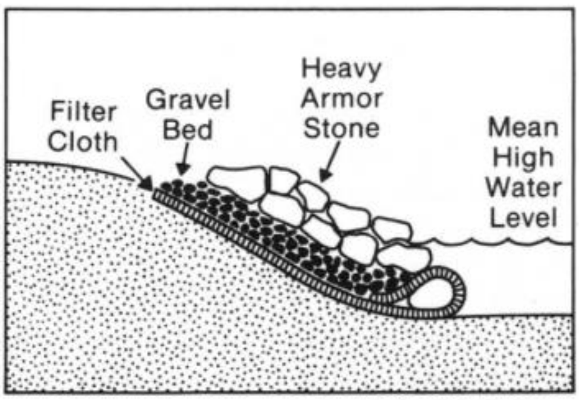


Figure 2-2 This rock rip rap revetment contains a filter layer, armour stone, and toe protection to prevent undercutting by scour. Reproduced from O'Neill Jr (2000).

Seawalls, Bulkheads and Quay walls

The terms 'seawalls, quay walls and bulkheads are frequently, and inappropriately, interchanged' (SPM, 1984). In certain cases, bulkheads are used to serve as seawalls and quay walls and vice-versa.

Seawalls

Seawalls are the most common type of coastal protection measures used in the RoM, and are sometimes referred to as onshore breakwaters (MHE, 2011b). They are onshore structures that are built parallel to the coastline 'with the principal function of preventing or alleviating overtopping and flooding of the land and the structures behind, due to storm surges and waves' (Ahrens, 1989). Seawalls are generally of heavier or more massive construction than bulkheads (SPM, 1984). The main difference between offshore breakwaters and seawalls are that seawalls have the capacity to act as soil retention structures while breakwaters do not. The other important feature of seawalls is that they are mainly for 'coastal protection and are not intended for use as berthing facilities' (Ahrens, 1989).

A 'seawall could be the last line of defence on an eroding coastline (Cummings et al., 2012). The physical form of these structures is highly variable; seawalls can be vertical, in the form of cribs or tie-backed and constructed from a wide variety of materials (Figures 2-3, 2-4, and 2-5). 'Seawall structures can be constructed as flexible rubble mound structures which are able to adjust to some toe and crest erosion, or as rigid wall structures which have a fixed form and position' (WRL, 2013).

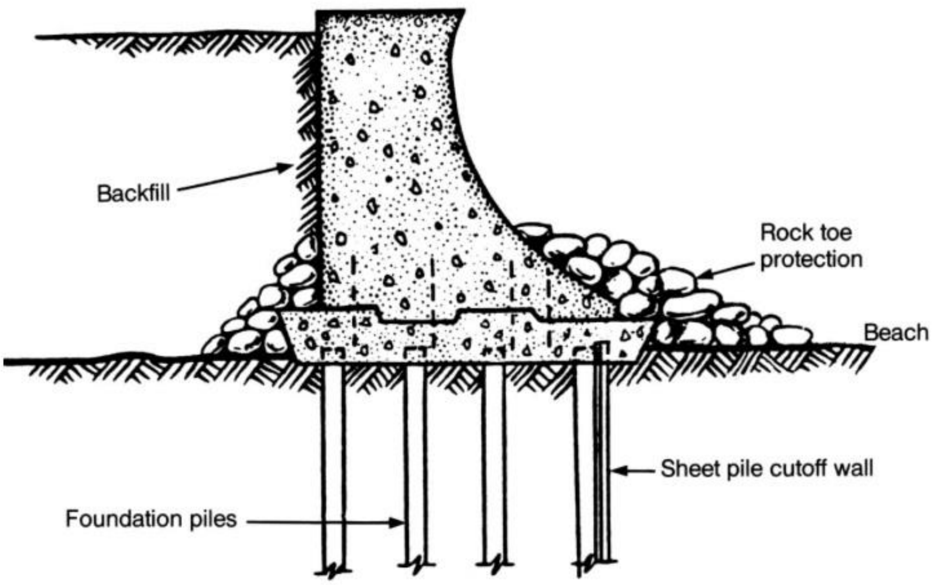


Figure 2-3 Curved-face (re-entrant) seawalls turn in a wave's energy against itself and are effective in severe wave climates. Wave run-up is held to a minimum. Reproduced from O'Neill Jr (2000).

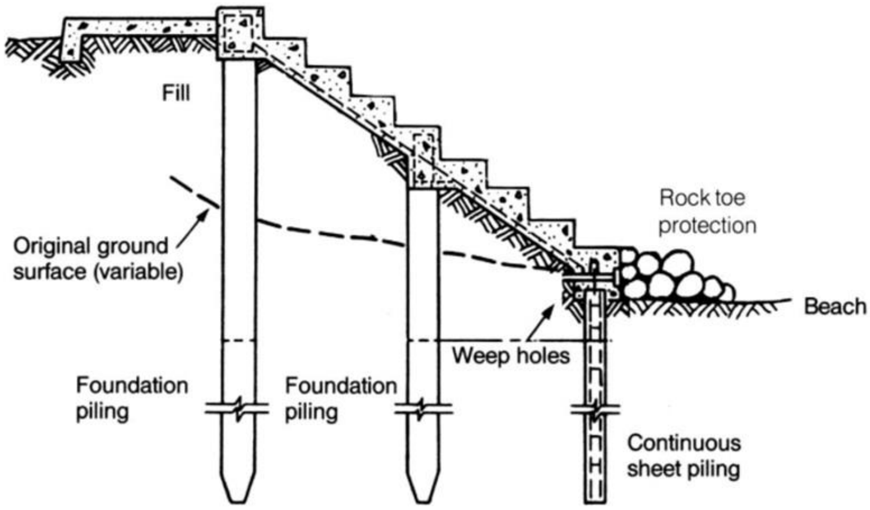


Figure 2-4 Stepped-face seawalls reduce the amount of wave run-up that can be expected. They work well in moderate wave climates. Reproduced from O'Neill Jr (2000).

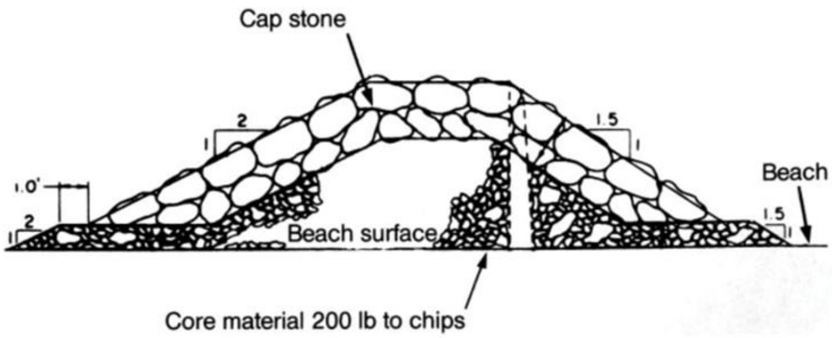


Figure 2-5 Mounds of rock rubble can be used to construct seawalls in the most severe wave climates. The amount of wave run-up on these structures is the least of all types of seawalls. Reproduced from O'Neill Jr (2000).

Bulkheads

Bulkheads are upright structures constructed parallel to the coastline, to prevent land from sliding, and to protect hinterland from beach erosion and wave interaction (Ahrens, 1989). They are generally of lighter construction than seawalls. The stability of bulkheads are derived either by mobilising 'passive earth pressures between the mudline and embedded tip' (Figure 2-6) or 'from lateral restraint systems installed between Mean Low Water (MLW) and top of the wall' (Terzaghi, 1954).

‘The primary purpose of bulkheads is to prevent the backfill from sliding while providing protection against light-to-moderate wave action’ (Navy, 1991; USACE, 1995).

Bulkheads are generally used as berthing facilities (Ahrens, 1989). Table 2-3 describes four different types of bulkheads: cantilevered wall, anchored wall, relieving platform and better piles.

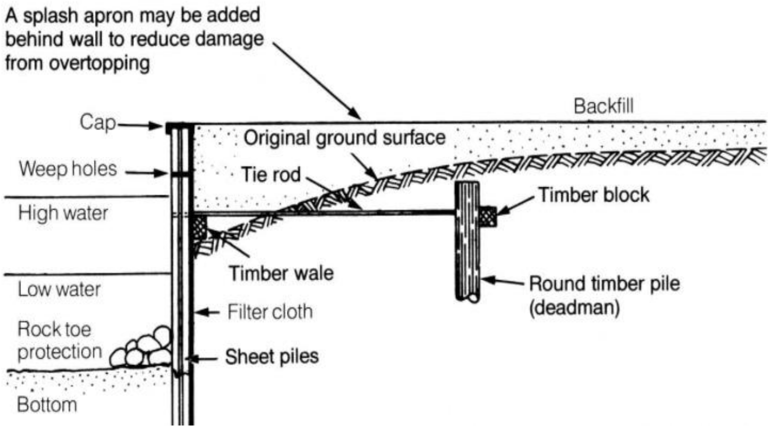
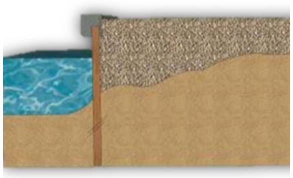
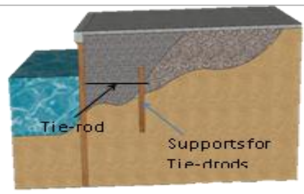


Figure 2-6 Anchored sheet pile bulkheads have anchors on their landward side. Reproduced from O'Neill Jr (2000).

Table 2-3 Bulkhead types and their uses (adapted from (Ahrens, 1989))

Bulkhead type	**Description**	
Cantilever wall		Deeper piling is required which increases cost and difficulty in driving. It is often less economical than an anchored wall. The principal advantage is less property encroachment and interference with adjacent assets.
Wall with single level of anchorage		This is the usual form of bulkhead (USACE, 1984). Supports for Tie-rods - Number as required to reduce unsupported length or tie-rods to 30ft max (to prevent excessive sagging)
Relieving Platform		Reduces lateral pressure on the sheets. It carries part of the weight of fill as vertical load to a deep level.
Battered piles		Battered piles are considered when there is a need to limit property acquisition

Quay walls

Quay walls are gravity wall structures parallel to the navigable waterways, and have the dual function of providing coastal protection and as a berthing facility for vessels. The functions of quay walls are similar to that of bulkheads and seawalls. However, quay walls are chosen over bulkheads when height and wave severity exceeds the practical capabilities of the bulkhead construction. 'Quay walls differ from seawalls in that they do not necessarily retain a soil backfill' (Ahrens, 1989).

Types of quay walls include steel sheet piles, timber cribs, concrete caisson, masonry or concrete blocks, cyclopean concrete, gabion wall, reinforced earth, stone mound, rubble mound, soil cement block etc. (Ahrens, 1989). Table 2-4 describes structural materials used for quay walls and their disadvantages.

The retaining function of quay wall structures is achieved 'by the self-weight of the structure, sometimes including the weight of the soil lying above it' (Regelgeving, 2005). On the main part of the seaward face where settlement may be expected and tide levels do not present great constructional difficulties, hinge joints are generally used to ensure flexibility in concrete quay walls (Thorn & Roberts, 1981b).

The 'weight of the soils on the floor slab of L-Wall helps to build up the shear stresses in the subsoil and ensures a favourable opposing moment in relation to horizontal soil pressures' (Regelgeving, 2005). When designing these structures, it is recommended that the designer must ensure that the wall to be constructed does not encourage erosion. One simple rule to be applied is to dissipate wave energy horizontally, not vertically, and special care should be taken on soft foreshores where erosion can occur at the toe of the wall (Thorn & Roberts, 1981b).

Table 2-4 Structural material used in quay wall and their main disadvantages

Structural Material	Disadvantages
Steel sheet piling	Subject to corrosion of sheet piles and tie-rods
Reinforced concrete	Subject to corrosion of reinforcement
Timber	Attack by borers
Concrete	Subjected to sulphate and chemical attack
Masonry structures	Subjected to repointing of joints

Breakwaters

Breakwater construction sharply increased in the 19th century, a trend which continued into the 20th century (Ramón et al., 2009). 'Breakwaters are shore parallel structures placed offshore to reduce or eliminate wave energy and contribute to deposition on beaches landward of them' (Dean & Dalrymple, 2004; Nordstrom, 2014; Usha & Gayathri, 2005). They are mostly used in high energy zones as a protection for the harbours, and as erosion mitigation measures where practical and feasible (Burkett & Davidson, 2012; MHE, 2011b). Breakwaters are generally placed out in the water to dissipate wave energy and to form a low-energy area on the landward side (USACE, 1981c).

When a breakwater is placed it restricts the offshore movement of sand from the portion of the beach face located landward of the structure (Sorensen, 1991). Beach profile adjustment in response to SLR then requires an additional volume of sand be removed from the beach face just seaward of the structure. The impacts of these structures 'will vary according to the type of coast in question' (Burkett & Davidson, 2012).

If the coast is to be managed in the most effective manner possible, it is necessary to adopt a solution where the coast can respond to movements in sea level wherever possible. Various types of breakwaters are used globally for the purpose of coastal protection and harbour activities (Oh & Shin, 2006; Usha & Gayathri, 2005). Breakwaters can be either fixed or floating (USACE, 1981a). The 18th International Conference on Navigation in Rome in 1953, divided breakwaters into two main classes: those from which waves are reflected and those on which waves break. Different types and shapes of breakwaters include vertical wall, curved, stepped, irregular, rubble mound and embankments etc. (Ahrens, 1989; French, 2001; Sorensen, 2005; Thorn & Roberts, 1981a).

The most common form of breakwater is rock armour breakwater. They are widely used around the world for the construction of artificial harbours and for coastal protection works (Neelamani & Vedagiri, 2002). Material weights, dimensions, and slopes will vary depending upon specific local water depths and design waves (O'Neill Jr, 2000) (Figure 2-7). Wave forces on the rock armours are high and they act on individual structures. Wave reflection on a rock armour breakwater increases water particle kinetics in front of the structure, which results increased toe scour, thus, sloped structures are recommended to overcome this drawback (Neelamani & Sandhya, 2005).

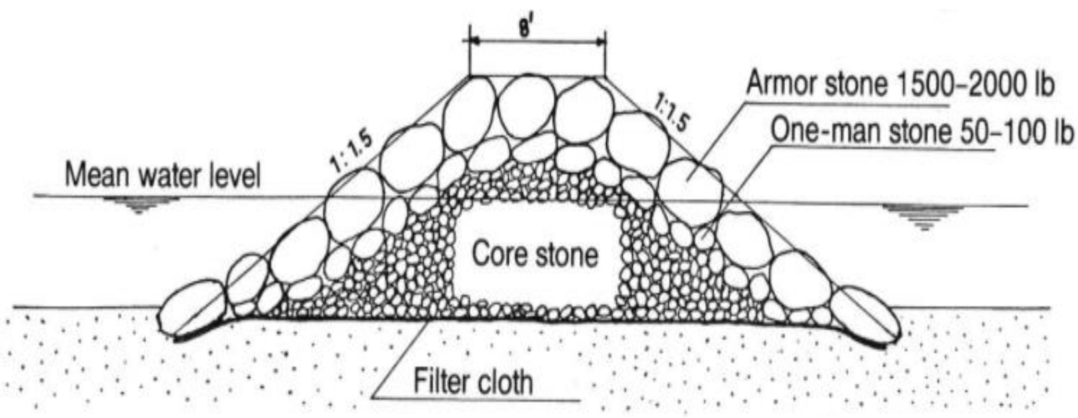


Figure 2-7 Rubble-mound breakwaters can be used in almost any depth of water and in almost any wave climate. Reproduced from O'Neill Jr (2000).

Basic research on rock armour breakwaters is often limited to stability, wave run-up, wave run-down and wave reflection of and on structures with no or only minor overtopping. In many cases, however, allowing a certain degree of overtopping is acceptable, and will lead to considerable savings on the quantity of material used (Van der Meer, 1999). The stability of over-topped structures is higher than for non-overtopped structures, because the energy of waves can pass over the crest, resulting lower wave impact on the armour layer of the seaward slope (van der Meer et al., 2005). Stability of these breakwaters depend on the properties of the mound material (armour weight and shape, under-layer size and shape, under-layer and core permeability), the foundation (toe support and detailing of the superstructure), and the hydraulic processes driven by wave action (Ahrens, 1989).

Gabions

Gabions are wire baskets or nets filled with either rocks or stones (Klingeman et al., 1984). Application of gabion as a coastal protection measure is common in different parts of the world (Neelamani & Vedagiri, 2002; Oh & Shin, 2006). Gabions are not easily displaced as they are enclosed, and the fill material acts as a group (Narayana Pillai & Verma, 1977).

Gabions are considered as a low cost and easy to install measure. Their flexibility, durability and permeability make it a popular protective measure in many cities of the U.S.A. (Klingeman et al., 1984). 'Gabions come in three basic forms, the gabion basket, gabion mattress, and gabion sack' (Freeman & Fischenich, 2000).

One of the main advantages of gabions is that it can be filled *in situ* by direct filling methods. Additionally, it can be implemented with lower costs and faster construction than other similar methods (Oh & Shin, 2006).

Gabions are frequently used in projects where the available rock size is too small to withstand the hydraulic forces present at a project location. When compared to rip-rap designs, gabions require approximately one third the thickness of material (Freeman & Fischenich, 2000).

Groynes

Groynes are coastal protection measures designed to trap littoral drift and, to some extent, the cross-shore sediment for creating protective beaches (Özölçer et al., 2006). Groynes are impermeable finger like structures constructed perpendicular to the shore, normally from shoreline to a sufficient water depth offshore (Cummings et al., 2012). They are usually constructed in groups called groyne fields. Groynes are, together with sea walls, one of the more traditional forms of coastal engineering and, as such, have a long history of use (Thorn & Roberts, 1981b). Groynes have served traditionally to prevent shoreline erosion on shorelines with significant alongshore transport (Dean & Dalrymple, 2004).

Jetties are used to protect and stabilise man-made constructions such as piers and other maritime works. In some areas, jetties are used to create harbours. Jetties are often not effective in preventing infilling of the channels; however, curved jetties may be designed to avoid depositional velocities (Pacheco et al., 2007).

Groynes and jetties are two well-known methods of building a beach naturally. However, these can be successful only, if there is a littoral drift or current parallel to the beach (Payne, 1980).

Groynes made of wood, metal or composite material usually have an effective service life of significantly less than fifty years and could be adjusted to SLR (Sorensen, 1991). As SLR occurs, the shoreward retreat of the MSL line might make the groynes and jetties susceptible to flanking during storms. Furthermore, any significant changes in the alongshore sediment transport regime might affect the functional behaviour of some of these structures, and require structure modification (Burkett & Davidson, 2012).

A saw-tooth configuration (Figure 2-8) is typical of a beach established using a series of groynes (a groyne field). Littoral drift is trapped on the upstream side of the groyne resulting in the fillets of sand (O'Neill Jr, 2000).

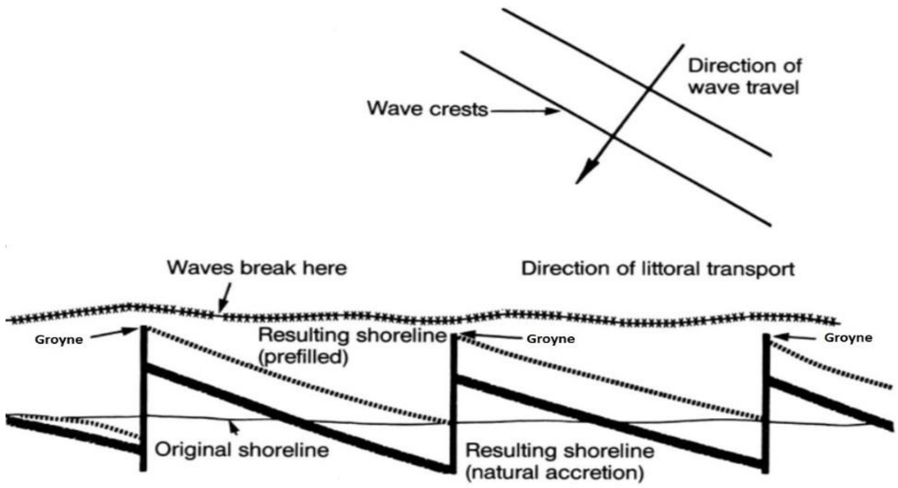


Figure 2-8 Groyne arrangement and wave interaction in a groyne field. Reproduced from O'Neill Jr (2000).

Timber groynes made of wooden piles and wooden sheet piling are common. A cross sectional view of such a groyne (Figure 2-9) shows the profile of a beach created behind the structure.

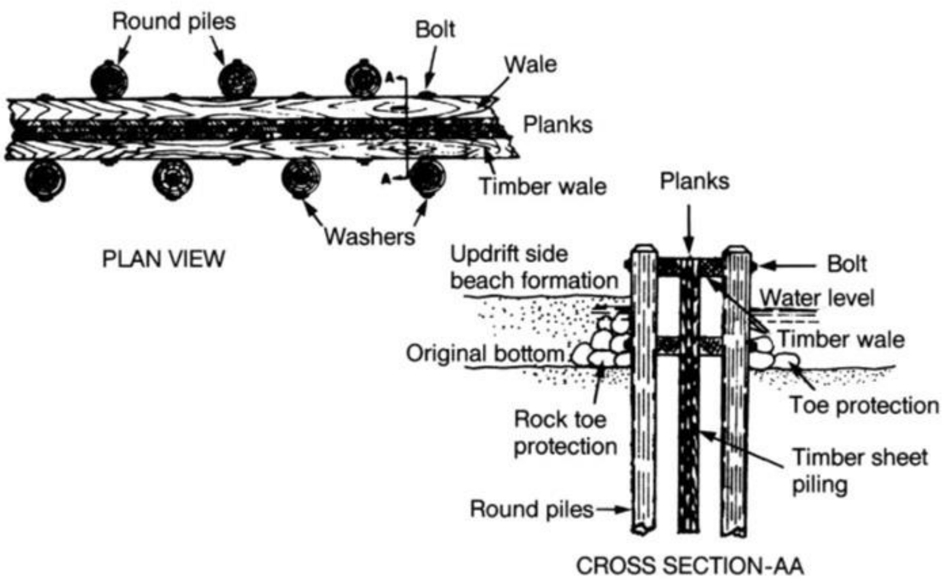


Figure 2-9 Plan view and cross section of wooden groyne . Reproduced from O'Neill Jr (2000).

There are five major types of groynes: template, permeable, T-head, Z, and round-headed groynes. Template groynes reduce sand and water diverted seaward by the waves and currents. They can potentially be raised and lowered seasonally, depending on the structure.

Figure 2-10 An access jetty-groyne in a resort island in the RoM

Permeable groynes allow sand and water to flow through the groyne. These permeable structures were found to be effective in retaining sand without apparent down drift effects. T-head groynes provide some diffractive shelter to the beaches at their base in order to mitigate the down drift erosion (Dean & Dalrymple, 2004). Figure 2-10 shows a long jetty constructed with a precast concrete slab on top. In addition, to facilitate sand retention at the beach it also provides berthing facilities to vessels.

Advantages and disadvantages of hard and soft coastal protection measures

For evaluating suitable measures for coastal protection, it is often important to compare advantages and disadvantages between different measures. The 'Structural Methods for Controlling Coastal Erosion' have identified some of the pros and cons of different coastal protection measures used in various countries (Tables 2-5 and 2-6).

Although, adaptation measures, their advantages and disadvantages are addressed in various literature sources, policy makers require decision support tools or frameworks to systematically evaluate their effectiveness and applicability against different coastal protection issues, and select feasible measures that can promote coastal safety and sustainability in a changing climate.

Table 2-5 General advantages of some of the coastal protection measures. Adapted from (Beca, 2010; Burkett & Davidson, 2012; McCue et al., 2012).

	Suitable for most wave climates	Do not deplete fronting beach	May build up beach by trapping littoral drift	Benefit down-drift shore & immediate area	Benefit long section of shoreline	Not subject to flanking	Few negative environmental impacts	Decrease local turbidity	Improve or do not restrict access	Provide direct boat access to the shore	Provide sheltered swimming/mooring area	Do not affect use of fronting beach	Provide more beach for shoreline recreation	May provide improved wild life habitat	Create opportunity for nature study	Relatively low cost
Reclamation		Y						Y	Y			Y				
Nourishment		Y						Y	Y			Y				
Vegetation		Y					Y					Y		Y	Y	Y
Revetments	Y						Y	Y						Y		
Sea walls	Y						Y	Y		Y						
Breakwater	Y		Y		Y	Y			Y		Y			Y		
Gabions	Y						Y	Y						Y		
Groynes			Y						Y				Y	Y		

Table 2-6 General disadvantages of some of the protection measures. Adapted from (Beca, 2010; Burkett & Davidson, 2012; McCue et al., 2012)

	May increase wave scour at toe	May increase erosion down drift	May decrease size of fronting beach	May cause steeping of fronting beach	Do not protect against direct wave action	Limit access to shore	Limit travel along beach	May limit use of fronting beach	May be hazardous to people walking on them	May cause bathing hazard from rip currents	Drop off into deeper water at sill may pose bathing hazard	Submerged sections may be navigation hazard	Increased turbidity may impair fishing	May impair water quality in still water between or behind structure	May reduce view from upland areas	Reduce amount of usable land at top of slope	Very susceptible to storm damage	Expensive to construct	Very difficult to repair
Reclamation					Y											Y			
Nourishment					Y											Y			
Vegetation					Y		Y												
Revetments			Y	Y		Y		Y	Y										
Sea walls	Y	Y	Y	Y		Y		Y										Y	
Breakwater	Y	Y										Y		Y				Y	Y
Gabions	Y																		
Groynes		Y					Y			Y		Y		Y					

2.3 DECISION SUPPORT FRAMEWORKS

Daniel J. Power (2013) and (Hayen, 2006) identified that frameworks are organised approaches demonstrating different parts of a topic and their interrelations. Decision support frameworks (DSF) therefore deal with multiple parts within specific areas of interest and become useful tools for complex decision making (Kouwen et al., 2008). The terms DSF, decision supports (DS), and decision support systems (DSS) are often used interchangeably. They are widely used in a number of contexts and are generally used to facilitate organisational decision makers to have substantial impacts in the decisions they make (Cohen & Condeluci, 2014). Apart from decision making, they often have the capacity to support unstructured problem solving and decision implementation (Le Blanc, 1991). Additionally, DSFs are broadly used in adaptation decision making where there is significant uncertainty (Swan River Trust, 2009).

Although, DSFs are expected to be simple and easy to use tools, misapplication can lead to unrealistic and misleading outputs (Parker et al., 1995). However, much of this can be overcome through careful designing of the frameworks, 'and ensuring the appropriate information is provided to the decision-makers about the limitations with system checks to avoid misuse' (Kouwen et al., 2008).

There is no universal definition of DSF as various authors have proposed different definitions (Hasan et al., 2017). Daniel J. Power (2013), defines it as a general concept that utilises interactive computerised systems and tools to assist decision makers use communication technologies, data, documents, knowledge or models, to identify and solve problems, complete decision processes, and make decisions. Similarly, (Iyalomhe et al., 2013)) defines DSF as a computer-based software that facilitates "decision makers in their decision process, supporting rather than replacing their judgment and, at length, improving effectiveness over efficiency". Another definition of DSF is that it is a system that is designed to enhances quality and effectiveness of both the process of decision making and its outcome (Arnott, 1998).

Similar to the definition, DSFs do not have universally accepted types or classifications (Hasan et al., 2017). Alter (1980) divided DSFs into two types; data-oriented, and model-oriented. Holsapple et al. (1996) classified DSFs into six different types; text-oriented, database-oriented, spreadsheet-oriented, solver-oriented, and rule-oriented. The combination of two or more types were classified as compound-oriented (Holsapple et al., 1996). Power (2004) grouped DSFs into five classes; data-oriented, model-oriented, document-oriented, communication-oriented, and knowledge-oriented.

Table 2-7 summarises a compilation of the types and descriptions of the DSFs from various authors.

Table 2-7 Types of DSFs and their descriptions (Alter, 1980; Hasan et al., 2017; Holsapple et al., 1996; Power, 2004).

Classification	Description	Reference
Data-oriented	The centre of focus in this type of DSF is the accessibility to large data files or data bases. These data bases provide structured data recorded for a long time. Decisions can be made by analysing these data.	Alter (1980),Power (2004), Holsapple et al. (1996)
Model-oriented	Relies on the data and parameter input by decision makers, hence does not need to depend on large database (Hasan et al., 2017). Models created on different contexts can be used for this type of decision making. For e.g. representation models, optimisation models, recommendation models etc.	Alter (1980),Power (2004), (Hasan et al., 2017)
Text-oriented	Users obtain information relevant to the decision making through accumulation of information received electronically over a period of time. This also allows decision makers to review and revise information received.	Holsapple et al. (1996)
Spreadsheet-oriented	Facilitates decision makers to view, analyse and modify information to make good decisions. It also allows to develop models to enhance decision outcomes.	Holsapple et al. (1996)
Solver-oriented	Utilises one or more solvers to make a decision whereby giving a particular problem to each solver. The outcome would be a combination of recommendation from solvers. Often seen in forecasting, planning, statistical, and optimization tasks etc (Hasan et al., 2017).	Holsapple et al. (1996), (Hasan et al., 2017)
Rule-oriented	Guides decision makers to arrive appropriate decisions by representing and processing the rules.	Holsapple et al. (1996)
Compound-oriented	Combines two or more types from text-oriented, database-oriented, spreadsheet-oriented, solver-oriented, and rule-oriented.	Holsapple et al. (1996)
Document-oriented	A very close type to text-oriented DSF. Users are supported via relevant documents and web pages retrieval and management.	Power (2004)
Communication-oriented	Facilitates enhancing the communication links between different users working on a same task. This is often seen used along with other type of DSF.	Power (2004)
Knowledge-oriented	Sometimes referred to as 'recommendation engines' (Cohen & Condeluci, 2014). Facilitates decision makers by recommending appropriate solution via its problem solving expertise (Hasan et al., 2017).	Power (2004), (Hasan et al., 2017)

Although DSFs facilitate users to make appropriate decisions, (Kouwen et al., 2008) found that DSFs do not holistically focus on complex decisions rather they focus only on some parts of the problems. To overcome this problem, (Kouwen et al., 2008) recommended to involve multiple decision-makers, multiple issues, and multiple disciplines in complex process such as coastal protection decision making.

There are no formal DSFs available in the RoM for coastal protection decision making (MEE, 2014). The closest to a coastal protection DSF in the RoM is the unpublished 'guideline for climate risk resilient coastal protection in the RoM' (McCue et al., 2012). The guideline consists of a compilation of international best practices for designing coastal protection measures based on recognised international standards, and provides engineering recommendations (McCue et al., 2012). The guideline has some attributes of a knowledge-oriented DSF and gives recommendation into integrating climate change considerations into the existing EIA process for coastal adaptation projects. It does not give a decision support framework for choosing between various measures.

RoM engineers sometimes use the USACE CEM as a reference manual, and it has a thought process for the design stage of CP projects (EPA, 2014). However, it is not evidenced from the interviews and research carried out that this thought process is followed systematically. The CEM thought process has ten stages: 1) Define project problem statement with the objective; 2) Quantify current and most probable conditions (without project); 3) Identify and analyze alternatives; 4) Select alternative; 5) Develop and test functional design; 6) Develop and test structural design; 7) Check for constructability, operation and maintenance, and life-cycle costs; 8) Select final plan, and prepare plans and specifications; 9) Construct project; and 10) Monitor and evaluate project performance (USACE, 2002).

Other documents that have some relevance to coastal protection decision making in the RoM include the 'Cost-Benefit Study of Disaster Risk Mitigation (CBSDRM) compiled for Three Islands in the RoM' (Venton et al., 2009), the 'Detailed Island Risk Assessment in the Maldives (DIRAM)' (UNDP, 2007), and 'Survey of Climate Change Adaptation Measures in Maldives (SCCAMM)' (MHE, 2011b). The objectives of CBSDRM were to review the Safer Island Program (SIP) concept to disaster risk reduction and to conduct a cost-benefit analysis (CBA) based on risk management measures identified for the SIP. It was built upon the reports UNDP (2006) and UNDP (2007). It identified various hazards that the study islands were exposed to, assessed the hazard impacts with and without coastal protection measures, and analysed the costs and benefits of each scenario used. It is not clear from the assessment what types of coastal protection measures were used, how resilient are the measures to multi-hazards, and what socio-economic and environmental costs or benefits are achieved or not achieved. The objectives of DIRAM study were to generate a comprehensive disaster risk analysis for 13 safer islands in the RoM, identify island specific issues, and recommend specific mitigation measures to make the islands safer (UNDP, 2007). However, taking a mitigation stance, the study avoided some of the key adaptation parameters that would otherwise contribute to improved resiliency in coastal protection measures in the RoM (Venton et al., 2009). Contrary to CBSDRM, DIRAM did not compare the costs and benefits of different coastal protection measures. SCCAMM was a survey conducted to provide a baseline information on adaptation activities in the RoM, and to identify existing measures that may be suitable for replication in the project. It covered a wide range of measures used in the RoM, identified the challenges and opportunities of soft coastal protection options, analysed costs and benefits of different measure (MHE, 2011b). It did not provide a mechanism to evaluate coastal protection measures for specific scenarios.

Additionally, a review was conducted on some of the coastal protection measures designed by Ministry of Housing and Infrastructure of the RoM to examine their environmental impacts on coastal processes (Kench, 2012a). The primary objective of the review was to examine alternative approaches to traditional methods of coastal protection in the RoM. However, it was identified that the structures used in the RoM were designed and utilised for harbour development projects but not coastal protection structures (Kench, 2010).

While, DSFs specifically for the purpose of coastal protection decision making are comparatively low world-wide, decision supports on the integrated coastal zone management (ICZM) are increasing, and resources on the subject are getting more available and accessible (Burkett & Davidson, 2012). Table 2-9 overviews a compilation of some of the coastal protection DSFs and decision supports used in broader area of ICZM that include the topic of coastal protection.

Table 2-8 Some of the coastal protection related DSFs and their functions. Adapted from (Kouwen et al., 2008) and (Rozum & Carr, 2013)

Name of the DSF	Description
Coastal zone Simulation Model COSMO	COSMO is a model-oriented DSF developed for the World Coast Conference in 1993, by the Netherlands Government (Haq, 1997). It allows coastal managers to evaluate management strategies under different scenarios, including long-term climate change (UNFCCC, 2013). It was used to identify the conditions under which beach material moves seaward, the rates of transport as functions of wave height and period, and explore the impacts of environmental and coastal protection measures.
CCORAL	The Caribbean Climate Online Risk and Adaptation Tool is a framework developed for Caribbean countries. It is a data-oriented climate resilient system designed to enable researchers and decision-makers to assess climate-influenced activities. It provides information on how the climate may influence their decision-making, and how impacts could be managed. It contains over 70 climate-related tools such as risks and vulnerability assessment, identification of adaptation options (financial and economic appraisal), and monitoring and evaluation. CCORAL helps to assess low, medium or high priority projects. Users with different expertise levels can use the tool. For non-experts, it provides guidance at a very basic level. Expert users are given options to skip guidance exercises and move directly into identifying comprehensive climate risk management process. It includes data on legislation, national planning, strategic policy, and financial evaluation. Case studies from different countries are available in the system.
Tyndall Coastal Simulator	Tyndall Coastal Simulator is a model-oriented DSF developed using the coast of Norfolk in East Anglia, United Kingdom. It integrates a range of models on storm surge flooding, coastal erosion, sea-level rise, and socio-economic scenarios. Using these models the DSF facilitates long-term assessment of impacts to the United Kingdom and helps to evaluate and make decision on environmental status, risk analysis, management strategies, uncertainty analysis, and integrated risk assessment (Mokrech et al., 2011; Nicholls et al., 2009).

ISLAND model	The ISLAND model is a document-oriented DSF developed for the United National Environment Programme, Caribbean Unit and presented during the ICM Conference on Small Island Developing States in Barbados, 1994 (Engelen et al., 1995). One of the advantages of the model is that it provides access to a number of resources concerning islands that, without the model, are otherwise difficult to obtain. It includes documents, educational materials, and a directory listing some 2,000 islands.
SIMCOAST	SIMCOAST is a compound-oriented DSF for worldwide coastal zones, initiated in 1995, and jointly funded by ASEAN and the EU. It uses model-oriented fuzzy logic and rule-oriented systems that enable researchers, managers and decision-makers to create and evaluate different policy scenarios for coastal zone management (Hogarth & McGlade, 1998). It also includes solver-oriented contents, where experts design parameters for their respective areas. The system is based on a two-dimensional transect of the coastal area. For each transect, the user defines the main features of each zone and the extent to which they play a role in each zone. This is defined either in terms of a crisp number (percentage) or as a fuzzy qualitative value. After the definition of the model, the user can review the definitions of the features and activities. The advantages of SIMCOAST include its flexibility in developing models for any coastal zone, capability of multiple interest groups and experts to take part in a workshop setting, and the ability to use of qualitative judgment and non-specific data in the fuzzy logic. The disadvantages include the time it takes to develop each application, and the requirement of multiple experts in developing the model.
CanVis	CanVis is a document-oriented tool developer by NOAA Coastal Services Centre to simulate the impacts of SLR and developments near the coastline. It can simulate impacts of various actions, compare impacts of different scenarios, and facilitate users to visualise future changes using imagery (photographs, satellite imagery, or pictometry). It does not facilitate users to evaluate different coastal protection options (Rozum & Carr, 2013).

DESYCO	DESYCO is a data-oriented DSF that helps in the regional risk assessment of climate change impacts in coastal zones. Processes in the DESYCO include: Sea-level rise, storm surge, Flooding, Coastal erosion, water quality. Functionalities include: Impacts and vulnerability analysis, Adaptation options definition, Multicriteria decision analysis, regional risk assessment (Torresan et al., 2016).
The CORAL model	The CORAL is a model-oriented DSF developed for Montego Bay in Jamaica, Curacao in the Netherlands Antilles, and North and South Male' Atoll in the RoM. It is a methodology developed by the World Bank for cost-effective coral reef management (Gustavson et al., 2000; Huber & Jameson, 1998; Westmacott & Rijsberman, 1995). It uses a mixture of simulation modelling, and fuzzy logic. Some costs are incorporated to help decision-makers select cost-effective solutions. It consists of an economic model, a water quality model and an ecological response model (Rijsberman & Westmacott, 2000). The model displays a structured approach to ICM decision-making, leading the user through a step-wise analysis of the planning process. The disadvantage of the system is its rigid structure and the inability to change certain parameters. The users could define different growth scenarios and management plans, and compare differences between various alternatives (Westmacott, 2001).
Shoreline Protection Guidelines for Kiribati (SPGK)	It is a knowledge-oriented DSF developed by Beca International Consultants (Beca) to the Government of Kiribati. It provides step by step information to the users in finding a limited number of applicable coastal protection measures. It provides some of the technical information including advantages and disadvantages of the measures proposed. It used information and a clear decision flow that could be useful for developing a DSF for the RoM.
SimLucia	SimLucia is a model-oriented DSF developed as part of a vulnerability assessment of low-lying coastal areas and small islands to climate change and sea level rise (Engelen et al., 1995). It was developed as an application of the generic modelling and decision-support framework to the island of St. Lucia, West Indies. The model has the macro and micro-scale of simulation. The macro-scale simulates the natural, economic, social and land-use environments (Engelen et al., 1995). The micro-scale simulates the situation over 40 years, or even shorter

	periods. The model is not objective driven and focuses on one indicator (criteria) that is the change in land use patterns. The main advantage of this modelling is the graphical output in the form of land-use changes. If the scenarios are already in place, the model is easy to use. The disadvantages include focusing only on changes to land-use patterns, low ease of adaptation of the scenarios, and the examination of the results (White et al., 2000).
SimCLIM	SimCLIM is a data-oriented DSF designed for the process of SLR, Coastal flooding, and Coastal erosion. Its Functionalities include: Environmental status evaluation, Impacts and vulnerabilities evaluation, Adaptation strategies evaluation, cost/benefit analysis (Warrick, 2009).
IPCC Risk and Vulnerability Framework	IPCC Risk and Vulnerability Framework is a data-oriented DSF included as a special report on 'Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation' in the 5th Assessment Report. Apart from the concept of climate risk (hazard, exposure, and vulnerability to climate stimuli), it includes incorporating risk exposure, sensitivity and adaptive capacity (IPCC). Compared to the 3rd and 4th assessment report, this report broaden out the concept and highlight the importance of exposure and vulnerability, highlight the very point of risk occurrence, when all three components interact, and bridge earlier disaster risk management and climate change vulnerability literature.
KRIM	KRIM is a data-oriented DSF. The processes include: SLR, Extreme events, coastal erosion. Functionalities of KRIM include: Environmental status evaluation, Adaptation measures evaluation, Information for non-technical user, Risk analysis (Schirmer et al., 2003).
A Bayesian Network to predict coastal vulnerability to SLR	Bayesian network to predict coastal vulnerability to SLR is a knowledge-oriented tool that applied Bayes' rule to evaluate potential SLR vulnerability for the Atlantic coast of the U.S (Thieler & Hammar-Klose, 1999). The data set used to make probabilistic predictions of coastline retreat include long-term relative SLR, long-term shoreline change rates, mean wave height, mean tidal range, geomorphic setting,

	and coastal slope. The tool assimilates important factors contributing to coastal change in response to SLR and can make quantitative, probabilistic predictions that can be applied to coastal management decisions. It facilitates participation between scientists and stakeholders when applied to management issues, and the outcome of the decisions can be improved by adding variables such as engineering structures (Gutierrez et al., 2011)
The Dynamic Interactive Vulnerability Assessment (DIVA)	DIVA is a compound-oriented DSF that integrates various databases and models, developed for the integrated vulnerability assessment of coastal zones to climate change and sea-level rise. DIVA comprises a coastal database, an integrated model of the natural system and socio-economic factors, and a graphical user interface for selecting data and scenarios, running the models, and analysing and visualising the results.
THESEUS	THESEUS is a data-oriented DSF with the processes including: SLR, Coastal flooding, Coastal erosion, Socio-economic scenarios. Functionalities of the DSF include: Vulnerability (Hydraulic, social, economic, ecological). Combination of engineering, social economic and ecologically based mitigation options, Multi-criteria analysis. High resolution risk assessment (Zanuttigh et al., 2014).
Sea Level Rise and Coastal Flooding Impact Viewer	SLR and Coastal Flooding Impact viewer is a rule-oriented tool developed by NOAA Coastal Services Centre to assess SLR impacts and coastal flooding to all U.S coasts except Alaska & Louisiana. Using pre-analysed data via web browser, it can assess inundation level, inundation, marsh migration, socio-economic impact, and coastal flooding. It is considered a user friendly tool that uses consistent data sets and analysis for coastal areas nationwide and allows users to visualize impacts of sea level at known locations. However, the inundation scenarios do not include coastal storm surge, erosion, or other coastal processes. Outputs of the tool cannot be customised or users cannot load additional local inputs into the tool for analysis. It does not facilitate users to evaluate different coastal protection options (Rozum & Carr, 2013).

The Risk Information System Coast (RISC)	The RISC is a document-oriented DSF that provides information on the probability of failure of dikes in the German North Sea coast, derived from water levels and geometry of the coastal zone. The consequences of dike failure are visualised including maps of flood zones and the calculation of loss and risk (Mai & von Leiberman, 2002).
HAZUS-MH Hazards–United States– Multi-Hazard	HAZUS-MH is a model-oriented DSF developed by Federal Emergency Management Agency (FEMA), U.S. to estimate socioeconomic losses from different hazards. The model is loaded with data required to run and complete analyses. Moreover, users can supply additional data if needed. It can be used to generate hazard characteristics maps, dollar value of the study region exposure, direct economic losses, facility functionality, shelter requirements, and debris. It can produce reliable results for large-scale events that can be used to plan for mitigation, emergency preparedness, and response. It can also provide results in easy-to understand graphic and tabular formats. It lacks inventory data and subsequently level 1 analysis functionality is unavailable for U.S. territories except Puerto Rico (Rozum & Carr, 2013).
SoVI Social Vulnerability Index	SoVI is a data-oriented tool developed by the University of South Carolina to synthesize socioeconomic variables that affect community preparation, response, and recovery from hazards. Using socio-economic and demographic input data of a county, it can standardize input variables, factor analysis components, total SoVI Score, SoVI classification (Low, Medium, High). It provides evidentiary information on capacities/capabilities for planning, decision making, and emergency response activities for the U.S (Rozum & Carr, 2013).
Coastal Engineering Manual (CEM)	CEM is a rule-oriented DSF developed by the USACE in 2002. It provides a ten step thought process in the planning and design of coastal projects. It provides detail information to engineers from problem identification to monitor and evaluate project performance. Some of the key process for selection of appropriate coastal protection measures in the manual include: definition of project problem statement with the objective, quantifying current and future conditions, Identifying and analyzing coastal protection measures, and selecting appropriate measures.

CommunityViz	Community Viz is a model-oriented DSF developed by Placeways LLC and the Orton Family Foundation for the purpose of visualizing, analysing, & communicating various planning decisions related to coastlines. Using variable input data sources such as GIS vector layers on parcels, zoning, roads and environmentally sensitive areas, demographics; population projections, future land use plans, or wizard based import of HAZUS-MH data, it analyses the impacts on various planning decisions. It also visualises different scenarios (illustrated by maps, charts, reports) measured by numerous impact indicators (environmental, economic, social, sustainability). It is identified as an interactive and highly visual decision support tool that has been widely used and well established, well supported, and frequently updated. However, it was also suggested that the tool has a limitation when it comes to make engineering-level designs. It is recommended for plans and directional decisions. It can be applied to any geographic scale from a small area to entire region (Rozum & Carr, 2013).
NatureServe Vista	Nature Serve Vista is a knowledge-oriented DSF developed by NatureServe to evaluate impacts of management scenarios on land use and conservation goals. It requires input data on the distribution of conservation elements of interest and land use/land cover. Also the expert input on conservation element viability requirements and response to stressors is recommended. It generates rich set of maps (ArcGIS grids), reports, and tabular outputs that can be exported to HTML and MS Excel formats. It works with and integrates information from many other tools, and covers many data integration, modelling, assessment, planning and adaptive management functions at multiple scales. It has raster-based platform which is a disadvantage for applications where maintaining precision of small features is important. It can be operated at any geographic scale with trade-offs at very large extents in raster resolution (Rozum & Carr, 2013).

All the DSFs evaluated in Table 2-9, except the CORAL and SPGK have been developed for countries that have different geophysical characteristics to that of the RoM. Even though, The CORAL used some information from the RoM and consists of a structured approach of decision making, its primary objective is coral reef management. And the rigid structure and inability to change important parameters limit its ability to use for coastal protection decision making. SPKG ticks some of the key objectives of a DSF that could be adapted for the RoM. However, it lacks in providing variability in types of coastal protection measures and the stakeholder involvement in the decision making.

Processes of some of the DSFs such as COSMO, CCORAL, Tyndall Coastal Simulator, DESYCO, SimCLIM, KRIM, THESEUS, and SPGK include coastal protection as a core element in the decision making. However, the technical evaluation of the options do not demonstrate the required objectives such as the technical viability, hazard resiliency and socio-aesthetics and environmental acceptability of different coastal protection measures that are expected to be achieved in a DSF for the RoM. Most of these DSFs are designed in a way to favour coastal management policies that use soft structural options (Research et al.) or no active interventions such as managed realignment and do-nothing, and discourages strategies that involve hard structural options (HSO) such as Hold the line (Defra, 2006; Leafe et al., 1998).

This preference towards SSOs can be addressed in the DSF to be developed through this research. Subsequently, technical knowledge together with various physical, engineering, economic and social factors of coastal protection measures identified through these DSFs will be used in the DSF. Moreover, with the information obtained through the literature on these DSFs, a logical and well-executed process of coastal protection measure evaluation and selection will be adopted for the DSF designed through this research.

As climate change and SLR together with cost implications of making the structures more resilient to coastal hazards are on the rise, the coastal protection measures are becoming increasingly more complex and difficult to assess (Kainuma et al., 1991). Additionally, the environmental issues are becoming more difficult to understand using one discipline, hence strategic assessment of different measures through decision supports and integration of various disciplines are paramount to strategic evaluation and assessment of appropriate measures (Te'eni & Ginzberg, 1991).

Regardless of the type of DSF used, its aim must be to achieve the required needs of the decision makers (Cohen & Condeluci, 2014). While, DSFs on the subject of coastal protection decision making are comparatively less, tools on the integrated coastal zone management (ICZM) are increasing, and resources on the latter subject are getting more available and accessible (Burkett & Davidson, 2012).

'Decision support tools are integration tools that can often incorporate analyses from multiple models, thus allowing them to address climate effects across a variety of sectors' (Rozum & Carr, 2013). Many of the ecosystem-based management tools often use GIS to make them more interactive and representative. There are three main types of tools used in ecosystem-based management planning; visualisation tools, modelling tools, and decision support tools. Apart from stakeholder engagement, visualisation tools often have the functionality of mapping. Modelling tools have the functionalities of analysis, scenario development and mapping. Decision support tools have the functionalities of 'data management, analysis, mapping, scenario development, and stakeholder engagement' (Rozum & Carr, 2013).

Although, various DSFs available on different disciplines of coastal protection are reviewed, no literature has been identified as a clear-cut procedure or framework that could be adopted to evaluate and select feasible coastal protection measures for the RoM context.

For the selection of appropriate coastal protection measures, decision makers may require a DSF that can take in various input data on the coastline in question, and 'provide a recommendation based on an analysis of those inputs'. Moreover, these DSFs should enable the decision makers the 'flexibility to take the recommendation, something close to it, or ignore it altogether' (Cohen & Condeluci, 2014).

2.4 Chapter Summary

A comprehensive literature review of different coastal protection measures and decision support frameworks were presented in this chapter. The characteristics, applications and uses for different measures were analysed and the pros and cons of hard versus soft measures was assessed. And various types of decision support tools and some notable DSFs that are used internationally in the coastal protection sector were also discussed. From the different types of decision supports discussed, comparison tool was chosen for the development of a DSF for coastal protection measure selection in the RoM. The interactive features in comparison tools help to compare side-by-side comparisons of different measures. Lack of systematic evaluation also increased cost implications in the repair and replacement of measures and created numerous difficulties in project initiation, implementation and maintenance. While this chapter evaluated common coastal protection measures used in the world, the next chapter evaluates the common coastal protection measures used in the RoM, and their advantages and disadvantages in the local context.

3 COASTAL PROTECTION MEASURES IN THE REPUBLIC OF MALDIVES

3.1 INTRODUCTION

Coastal erosion and coastal flooding are prevalent on a large number of islands across the RoM (Wadey et al., 2017). The low-lying nature of the islands, their geographic dispersion, their environmental fragility and limited financial resources further exacerbate the country's vulnerability to multi- hazards (MEE, 2015). Additionally, the settlement footprints of all islands and the country's entire resort infrastructure are within 100 m from the coast. In 2013, 67 percent of inhabited islands reported beach erosion (MEE, 2015). Consequently, severe erosion and coastal flooding could impact adversely on the economy as well as could pose a serious threat to lives and livelihoods of the communities. Therefore, appropriate adaptation and coastal protection measures are urgently needed to safeguard the human settlement and economy of the RoM (MEE, 2015).

This chapter examines different coastal protection measures used in the RoM and summarises their advantages and disadvantages with regard to technical viability, multi-hazard resiliency, and socio-aesthetics and environmental acceptability. It is important to note that the majority of the measures are used in the RoM are adapted techniques from other countries that have no or very little technical information in any of the literature sources available in the RoM. Therefore, this chapter summarises information on the measures identified from the researchers empirical knowledge, information acquired through the surveys conducted in the RoM for this research, and a comprehensive literature review conducted on the same measures abroad. The measures are presented the way they are implemented in the RoM context unless a vast difference is observed in the application and implementation in the measure in global context. In such cases, both methods will be discussed.

3.2 EVALUATION ASPECTS OF COASTAL PROTECTION MEASURES

Coastal erosion and coastal flooding were considered relatively small scale problems about 50 years ago (MEE, 2014). The possible reasons could be that coastlines were undisturbed and islands had space available (low population) for relocation when coastlines near them had been impacted by coastal erosion or coastal flooding (Mimura & Nunn, 1998). Although the scales of coastal protection problems were small, indigenous coastal protection measures were used in some of the islands. These *ad hoc* measures rely mostly on the material and other resource availability, simplicity of implementation, and the technological knowhow of the local communities. Application of *ad hoc* measures, the use of unsuitable materials, and the consideration of erosion as a local matter, in many cases, intensified the problems they were designed to solve which required expensive repair, maintenance and rebuild (Dias et al., 2003).

Male', the capital city, was the first island that used engineered structures that followed design controls for coastal protection in the RoM. After a series of high tides flooded more than half of the city first in April 1987, and then in June and September 1988, the Japanese Government granted aid to construct sea walls along the coast of Male' (Morimoto, 2001). The West, the East, the South and the North coast seawalls were completed in 1996, 1998, 2000, 2002 respectively (MHI, 2014).

Although, the coastal protection measures used in the RoM have evolved over the years from adapted techniques and *ad hoc* measures applied by island communities (MHI, 2014), Kench (2010) identified that only few of the measures follow formal design guidelines (MHE, 2011b). Kench (2010) also stressed that customizing the measures to the RoM coastline is crucial, maintaining that borrowed designs from other countries disregard the unique process characteristics of reef islands.

Responses to coastal erosion and coastal flooding problems in the RoM currently focus on the technical aspects alone (MTCC, 2014). Because of the absence of evaluation tools, the key aspect in deciding measures is whether they are capable structurally to stop coastal erosion or not (MEE, 2014). On the other hand, Dean and Dalrymple (2004) and Beca (2010) identified that technical viability, financial feasibility, and social acceptability and other relevant factors are important aspects to assess before deciding a measure. Apart from financial feasibility, Kamphuis (2010) agreed on the other two aspects, technical viability and social acceptability as main aspects.

Pilarczyk (1990) and Banton et al. also agreed on technical viability as the key decision parameter and identified constructability, maintenance, design reliability as important factors to consider. Durability and ease of construction are important factors that considers technical viability of a measure (Beca, 2010; Nicholls et al., 2007a). Understanding the characteristics of measures and the knowledge of the location where they are being applied can be useful information for a proactive coastal protection approach (Pope, 1997). In this regard, the measures contribution to erosion down-drift, its effectiveness in protection against direct wave action, its simplicity in the construction that requires less skilled labour, and less machinery & equipment are important factors in evaluating technical aspect of a measure (Pilarczyk, 1990).

Resiliency to multi-hazards is another important design parameter for coastal protection measures because it is vital for structures to survive amidst environmental and natural catastrophes (Barnard et al., 2009). 'Coastal Risk Reduction and Resilience: Using the Full Array of Measures' by Bridges et al. (2013) acknowledged the structural resilience of common coastal protection measures to coastal erosion, storms, coastal flooding and sea level rise. Although it is not a common practice everywhere to include multi-hazards such as earthquakes and tsunamis in coastal protection measure design, they were considered in the designs of coastal protection measures implemented in the region of the '2011 Tohoku-oki earthquake and tsunami' in Japan (Mori et al., 2013). UNDP (2007) identified potential hazards to the RoM and acknowledged the possibility of controlling the impacts of hazards using engineered coastal protection measures. The natural hazards prevailing in the RoM include: geological hazards (e.g. earthquakes and coastal erosion), meteorological hazards (e.g. tropical cyclones), hydrological hazards (e.g. storm surges, tsunamis and swell waves), and climate change related hazards, such as sea- level rise (UNDP, 2007).

Other important decision parameters in evaluating coastal protection measures include their social, aesthetic, and environmental aspects (Klein et al., 2001). While Robertshaw et al. (2012) agreed aesthetics is an important aspect for evaluation, Beca (2010) advised to consider both social and environmental aspects. USACE (1995) also recommended that evaluation of different coastal protection measures should involve examination of their economic, technical, and environmental aspects, and stressed further the importance of aesthetics features such as the nature and attractiveness of material, and amenity values due to aesthetic features in the evaluation. O'Neill Jr (2000)identified some of the social and environmental factors that could be used in the evaluation of alternative coastal protection measures. The social factors include: (1) the possibility of measure becoming a navigational hazard, (2) the likelihood of it becoming hazardous to people walking on it, (3) the chances of it limiting views from upland areas, (4) the likelihood of it providing sheltered mooring areas, and (5) the risk of it limiting the beach use. The environmental factors include: (1) the opportunity it provides in improving marine/wild life habitats, and (2) the risk of increasing local turbidity if a measure is implemented.

3.3 Application/Implementation of Coastal Protection Measures in the Republic of Maldives

A wide range of coastal protection measures that provide engineering solutions to coastal erosion, coastal flooding and other climate change related issues have been used in the RoM (Kench, 2012b). Table 3-1 shows the commonly used coastal protection measures in the RoM identified through a literature review and surveys conducted in the RoM (Chapter 5 and Chapter 6). The coastal protection measures in the RoM are grouped into 'soft coastal protection options' and 'hard coastal protection options'.

Table 3-1 Common coastal protection measures in the RoM

Soft Structural options					
Technical Category	***Reclamation***		***Nourishment***		***Vegetation***
Measures	• Land Reclamation using excavators, cutter suction dredgers, and trailing suction hopper dredgers		• Beach Replenishment using sand pump and excavators		• Planting
Hard Structural options					
Technical Category	***Breakwater***	***Revetments***	***Seawalls/bulkheads***	***Gabions***	***Groynes***
Measures	• Rock Armour • Tetrapods • Sand cement bags • Geo-bags • Concrete caisson • Steel Sheet piles	• Sand-cement Bags • Concrete • Rock Armour	• Concrete piles • Steel Sheet piles • Sand cement bags	• Steel wires • Geosynthetic mesh	• Sand cement bags • Armour rock • Geo-bags

3.4 Soft Structural Options

Soft protection options are coastal protection measures that try to improve 'the natural features as an option for adaptation' (MHE, 2011b). They may be used where there is a need for continued intervention to achieve a specific outcome. The overall aim of soft protection option is that management of the shoreline would be enhanced by either allowing or creating the conditions for the coast to realign (McCue et al., 2012). Common soft coastal protection measures in the RoM include reclamation, beach nourishment, and vegetation (MEE, 2016; MHE, 2011b).

Whilst hard protection options combat wave energy; soft measures aim to dissipate it using natural coastal processes. 'This results in low maintenance coastal systems that are able to respond to external forcing factors such as storms and sea level rise' (Cooper & Mckenna, 2008). There is a growing interest in soft coastal protection measures mainly as the cost of hard approaches and their repair and maintenance continues to rise (Basco, 1998).

The results of soft coastal protection measures are more natural, provide a good level of protection, diminish negative environmental and landscape impacts, are generally considered less expensive and more effective over a long term (Basco, 1998; Basco, 2001; Bijker, 1989; Koster & Hillen, 1995). However, the need of continuous maintenance is a disadvantage in such measures (Dias et al., 2003).

Many projects that have initially used hard coastal protection measures have been modified or combined with softer options in Europe (Pilarczyk (2003). Because of the lower initial cost and easier implementation, they may be a good alternative for coastal protection in developing countries (Pilarczyk (2003). In the last decade, more soft measures were adopted in Italy as the authorities identified the beaches protected with hard structures modified the coastline, escalated down-drift erosion, and increased maintenance costs (ADB, 2010). Although, soft coastal protection measures were encouraged in some of the research, it is important to understand that these measures are found to be effective only in areas where coastal erosion does not constitute a risk, thus, the positive long term impacts of these measures may be optimized by combining them with hard structures (Salman et al., 2004).

Soft coastal protection measures have not been properly demonstrated in the RoM 'due to the lack of awareness and foresight to consider erosion mitigation measures before they become a threat to existing property' (MHE (2011b).

The following section discusses various soft coastal protection measures used in the RoM. It compiles information on different coastal protection measures currently being utilized to combat coastal erosion and coastal flooding in the RoM.

3.4.1 Land Reclamation

Land reclamation is defined as 'the gain of land from the sea, or wetlands, or other water bodies, and restoration of productivity or use to lands that have been degraded by human activities or impaired by natural phenomena' (OECD (1991). It is an affordable method of coastal protection in areas where wave actions are low throughout the year. If the annual replenishment rate is not too high, the cost of reclamation is much desirable than the corresponding costs for a hard structural option (Thorn and Roberts (1981a). One of the environmentally attractive qualities of reclamation is it aims to dissipate wave energy in the same way it is dissipated in natural systems (French, 2001).

Different scales of reclamation have taken place in many inhabited islands of the RoM (Kench, 2010). In the past, small scale reclamation need to be common in islands where harbor development projects took palce. Reclamation of 200 ha of land at the eastern lagoon of *Hulhule'* in *Kaafu* atoll (later named *Hulhumale'*) was the first large scale reclamation project in the RoM (Ozan et al., 2012). The success of Hulhumale' reclamation project led the government to initiate a programme to reclaim potential island for population and development consolidation in 2008. Some of the landmark reclamation projects under this scheme include, Kaafu Thulusdhoo, Dhaalu Kudahuvadhoo, and *Baa Eydhafushi* island reclamation project. Reclamation projects bring significant changes to the existing coastline. Figures 3-1 and 3-2 show sand bunds set-up around the proposed reclamation area, and an ongoing reclamation project respectively. In some islands like *Lhaviyani Naifaru*, the reclamation project entirely transformed the footprint of the islands (Kench, 2010). Since then, land reclamation has been practiced at different scales in various islands of the RoM. Combined with hard protection measures, it is becoming increasingly popular in coastal protection in the RoM (MHE, 2011b).

Figure 3-1 Proposed area for Gaafu Alifu Villingili reclamation project ready with sand bunds. Photo credit: Iqbal Fikry

Figure 3-2 Reclamation project in progress in an Island of the RoM

As the demand for land expansion and the scale of reclamation projects increased in the RoM, internationally renowned methods of reclamation such as reclamation using cutter suction dredgers and trailing suction hopper dredgers (TSHD) were adopted to speed up recent reclamation projects (MHI, 2014). Some of the reclamation projects in the RoM used material dredged from other areas of the same lagoon (e.g. Gaafu Dhaalu Thinadhoo and *Lhaviyani Naifaru* Island) while material from nearby sand banks were also used in reclamation projects (e.g. *Raa Kandholhudhoo* Island) (MHI, 2014).

Reclamation is an effective coastal protection measure for areas that experience longterm degradation of coastline mostly due to human interventions. They are not advised to coastlines that are exposed and subjected to strong currents, strong wave actions, frequent storm surges, and intense turbulences (Bard & Riepl-Thomas, 2000). Table 3-2 summarises the advantages and disadvantages of land reclamation.

Table 3-2 Advantages and disadvantages of Land Reclamation

Advantages	Disadvantages
• The natural appearance of beach can be enhanced by reclamation that creates more opportunities for recreation and tourism • Materials go along with the natural processes without any adverse impacts on adjacent areas of the coastlines • The raised land by reclamation increases the resiliency towards overtopping and coastal flooding. It also provides a degree of protection to the area behind it, while in most cases creating more land for recreation (USACE, 1981b) • It helps to retain sand volume for coastline stabilization • Less reflective than a hard wall. Dissipates waves energy and reduces overtopping • Encourages coastal vegetation to take place whereby providing additional reinforcement to the ridge	• Additional land mass created sometimes attracts new development closer to the vulnerable coastal areas, putting lives and livelihoods at risk • In some cases, it increases hazard exposure of islands • It has some negative impacts on coral reef environment such as turbidity, siltation on the coral reefs etc. • Does not control severe erosion • Loss of material during transport and placement • Relatively large amount of material is required

3.4.2 Beach nourishment

The losses due to coastal erosion and flooding by artificially placing material on a coast (Beca, 2010). Nourishment is one of the popular soft coastal protection options used in resort islands as it is aesthetically appealing and generally considered an environmentally benign strategy (Davis et al., 1992; Kench, 2010). It provides a buffer for hinterland assets, thus, further replensihment is required once the initial design life is exceeded (Beca, 2010).

Beach nourishment has a long history of application in many developed countries around the world including Australia, Europe and America (Cummings et al., 2012). It has also been used in developing countries such as Brazil, South Korea and Malaysia (Fletcher et al., 2013).

Beach nourishment is an effective solution to counteract coastal erosion caused by long-term SLR (Bird, 1985; Gornitz et al., 2001; Raudkivi & Dette, 2002; Stive et al., 1991 ; van de Graaff et al., 1991). Performance of replenishment projects depend on many factors including length, width and orientation of the beach (Roberts & Wang, 2012). The volume of material required for replenishment must be sufficient to compensate the losses due to ongoing erosion. It must also be sufficient to adjust between nourished and equilibrium profile, and balance the losses during transport and placement (Beca, 2010). Effective management of the replenished beach requires periodic re-nourishments (Smith et al., 2009).

The material for beach nourishment are mostly obtained from permitted sand-mining grounds and transported to site. Figures 3-3 and 3-4 shows stock piling of sand at a permitted sand-mining ground by an excavator, and the material being transported on a spud barge to the proposed replenishment area respectively.

Figure 3-3 Stock piling of sand at a mining ground near *Gaafu Dhaalu Fares Maathodaa* using an excavator

Figure 3-4 Transporting sand to proposed replenishment area on a spud barge

Some larger projects rely on dredged material acquired using sand pumps. In some cases, material is obtained from harbour dredging (McCue et al., 2012). Unlike reclamation, nourishment generally does not require mechanical methods of compaction for settlement.

One of the technical setbacks of nourishment is the inapprorpiate designs induced by lack of understanding of sediment process in a specific area (Salman et al., 2004). Improper designs of nourishment to high energy conditions and coasts with steep foreshore, the nourishment material can move quickly to offshore direction requiring more re-nourishment (Salman et al., 2004). Kench (2010) identified that the success and viability of a nourishment project depends on the design. Hence, he suggested to consider sediment grade and durability, nourishment volume, and placement as critical design considerations. The frequency of replensihment depends upon the severeity of wave action, frequency of storm surges, and the grain size (O'Neill Jr, 2000). Suitable locations for beach nourishment would be sandy coasts, coasts that have other sand retaining coastal protection measures implemented (Beca, 2010), coastlines suffering erosion due to channel dredging (Scottish Natural Heritage, 2017). Table 3-3 summarises the advantages and disadvantages of beach nourishment.

Table 3-3 Advantages and disadvantages of Beach Nourishment

Advantages	Disadvantages
• Appearance of the coastline can be enhanced by nourishment projects. These projects also create more opportunities for recreation and tourism (Nicholls et al., 2007c) • Use of similar material to that of existing coastline helps to retain natural beach processes (McCue et al., 2012), supports to keep the coastline in equilibrium (Brunn, 1952), and hence, does not aggravate impacts on adjacent areas of the coastline (Davis et al., 1992). • Nourishment mitigates the impacts of longshore transport (Salman et al., 2004), dissipates wave energy, and reduces overtopping (Beca, 2010) • Do not require mechanical methods of compaction for settlement	• In severe environments, frequent replenishment is required to balance the losses from coastal erosion. In the RoM, only the resorts that have the financial capacity to maintain such schemes sustainably can afford it (McCue et al., 2012). • In most cases, a continuous supply of material from a nearby area is required and can be difficult to obtain (Fletcher et al., 2013). • Does not control severe erosion (Beca, 2010) Relatively large quantities of nourishment material are required since a significant amount of material will be lost during transport and placement (Beca, 2010)

3.4.3 Vegetation

Vegetation is a cost-effective and generally an easy approach used for stabilizing low-energy coastlines from erosion by planting desired species of vegetation along the coastline (BOP, 2002). They cannot always control erosion, thus, is not applicable to all situations. Vegetation can be combined with a hard structural option to prevent severe erosion (USACE, 1981b). Figure 3-5 shows a combined approach of hard coastal protection measure with vegetation applied to protect a coastline in the RoM. The narrow fringes of vegetation along the coastlines in most of the islands although help to reduce the impacts of wave action on coastlines, they are not effectively maintained in a sustainably way (MEE, 2014). Table 3-4 summarises the common types of vegetation (herbs, shrubs, vines and plants) that thrive in the brackish coastlines of the islands of the RoM.

Figure 3-5 A combined approach of vegetation and hard coastal protection measure used in *Shaviyani Feevah* Island of the RoM

Table 3-4 Common types of vegetation seen along the coastlines of the islands of the RoM

Common name	*Dhivehi* name	Common name	*Dhivehi* name
1- Sea lettuce	*Magoo*	9- Ironwood	*Kuredhi*
2- Sea Hibiscus	*Dhiggaa*	10- Banyan Tree	*Nika*
3- Beach Gardenia	*Uni*	11- Indian Almond	*Midhili*
4- Pandanus/Screw Pine	*Maakashikeyo*	12- Portia Tree	*Hirun'dhu*
5- Tree Heliotrope	*Boashi*	13- Lantern Tree	*Maskan'dhu*
6- Sea Trumpet	*Kaani*	14- Alexandrian Laurel	*Funa*
7- Beach morning glory	*Thanburu*	15- Grey Nickernut	*Kashikunburu*
8- Indian Mulberry	*Ahi*	16- Poison Bulb	*Maakan'dholhu*

Vegetation helps to dissipate wave and tidal energy, trap littoral sediments, and provide protection against mild coastal erosion, however, is considered not effective protection against coastal flooding and severe erosion (Beca, 2010). Coastlines protected with vegetation are more stable than the coasts where vegetation has been disturbed and removed (Mimura & Nunn, 1998). Vegetation is very effective in mitigating the damages caused by storms (Salman et al., 2004). Additionally, they are identified as an effective protection measure against tsunami since they help to reduce wave height and energy. Analytical models by Danielsen et al. (2005) identified that '30 trees per 100 m in a 100-m wide belt may reduce the maximum tsunami flow pressure by more than 90%'. Table 3-5 summarises the advantages and disadvantages of Land Vegetation.

Table 3-5 Advantages and disadvantages of Land Vegetation

Advantages	Disadvantages
• Inexpensive and easy approach • Stabilize low-energy coastline by dissipating reducing wave amplitude and energy • Improves the beauty of a coastline (USACE, 1981b). • Helps to grow the coastline by littoral drift (Beca, 2010) • Increase the strength of the top soil layer • Blends in with natural surroundings and may create wildlife habitat	• Cannot prevent erosion in high-energy conditions • Needs to be combined with another structural option to control severe erosion • Continuous maintenance is required • Takes time for the measure to become effective (USACE, 1981b)

3.5 HARD STRUCTURAL OPTIONS

Hard engineering measures are the most widely implemented coastal protection and adaptation measures in the RoM (MEE, 2016; MHE, 2011). They prevent sediment contributing to coastal processes by locking the material into the land whereby altering the coastal sediment transport processes (Beca, 2010). Hard coastal protection approaches are used within inter-tidal zone to reduce wave energy, control the disruption of coastal erosion to stabilize shorelines, to stop the sea from interacting with the hinterland, and to limit the amount of sand being transported by longshore movement. The principal purposes of hard engineering measures are to provide calmer, accessible mooring shelters, and reduce or mitigate the impacts of wave overtopping in order to prevent flooding and inundation in low-lying areas (Thorne et al., 1995). In most cases, hard coastal protection approaches tend to fix the coastlines in position and hence allow no flexibility in response to external variables (French, 2001).

Disadvantages such as inducing down drift erosion, increasing beach reflectivity, augments and starvation causing chain reaction resulting in an entire coastline fronted by protective structures have been linked to the application of hard options (Dias et al., 2003). These disadvantages or negative impacts in many cases are not because of the hard structural options but the results of ‘poor design and construction, mismatch between site condition and design (for example, a generic template is used across all islands regardless of the hydrodynamic conditions and sediment flow patterns), inadequate maintenance, less durable material like sand-cement bags, *ad hoc* replication of design across islands without considering their applicability to a new setting, erosion prevention measures are usually implemented in the 'last-minute', making the use of 'hard' measures compulsory'(MHE, 2011b). Not all the hard structural options in the RoM follow formal design guidelines (MHI, 2014). Kench (2010) identified that several key factors are ignored in designing, designs are typically recycled from previous projects or adapted from other countries without considering the unique process characteristics of reef islands, and the guidelines used in selecting material and methods of construction also disregard 'most standard measures of sound engineering design'. Table 3-6 shows the main classes of hard coastal protection approaches and the different coastal protection measures in the RoM.

Table 3-6 Some of the hard coastal protection measures and the common terminologies used in the RoM to categorise them. Reproduced and adapted from (MHE, 2011b)

Technical Category	Seawalls/ Bulkheads	Revetment	Breakwater	Groynes	Gabions
Geometry or Location	• Vertical • Crib • Tie-backed	• Sloped	• Detached • Single • System • Submerged	• System (field) • Single • Straight line • Shaped (T, L or lollypop)	• Detached • Single • System • Submerged
Materials	• Concrete piles • Steel Sheet piles • Sand cement bags	• Sand-cement Bags • Concrete • Rock Armour	• Rock Armour • Tetrapods • Sand cement bags • Geo-bags • Concrete caisson • Steel Sheet piles	• Sand cement bags • Armour rock • Geo-bags	• Steel wires • Geosynthetic mesh

3.5.1 Breakwater

Breakwaters are structures built generally offshore, aligned parallel to the coastline, intended to reduce wave energy reaching the coastline (O'Neill Jr, 2000), and 'located either individually at transition points or in groups over longer lengths' (Crossman et al., 2003). Dean and Dalrymple (2004); French (2001) also agreed the breakwaters work on the principle of reducing the wave energy reaching the coastline rather than physically impeding the alongshore transport of sand. They are generally placed on the reef flat (Kench, 2010) and provide safe havens for boats, dredging equipment, or bathers (Dean & Dalrymple, 2004).

The initial costs of breakwaters are found to be costly, frequent maintenances are required in high energy conditions, and beach aesthetics are compromised (Dias et al., 2003). However, the actual service lives may often exceed one hundred years for some of the breakwater options making it more cost-effective in the long run (Forbes et al., 2004).

The crest elevations of breakwaters are relatively easy to raise giving them the capability of retrofitting if required. However, the increased wave heights, due to sea level rise, storm surges and swell waves, require larger armour units to maintain structural stability. As sea level rises, the shoreward retreat of the mean sea level (Bridges et al.) makes the structures susceptible to flanking during storms (Sorensen, 1991). Any significant changes in the long-shore sediment transport regime might affect the functional behaviour of some of these structures and require structure modification.

Breakwaters are widely used and have been one of the most common coastal protection measures in the RoM. They are an effective measure in dissipating wave energy. While the height and porosity of breakwaters determines how effective they are in dissipating wave energy, they trap sand moving both parallel and perpendicular to shore Breakwater construction sharply increased in the 19th Century, a trend which continued into the 20th Century (Ramón et al., 2009). They are regarded as one of the most effective coastal protection measures because of their ability to prevent severe erosion and protect hinterland from flooding by acting as a physical barrier between land and sea (French, 2001). Usha and Gayathri (2005) also identified that breakwaters are effective means of intercepting wave energy before it erodes the coastline. Breakwaters are constructed using different materials and have various types and shapes. In the RoM context, the types may be detached, single, or submerged (MHE, 2011b). Shapes of breakwaters are sometimes vertical, curved, stepped, or irregular in face (French, 2001; Sorensen, 1991; Thorn, 1960). They may be constructed using materials such as rock armors (rubble mound), tetrapods, sand cement bags, geobags, caissons, and steel sheet piles (French, 2001; MHE, 2011b). Breakwaters can alter wave refraction and current processes and sometimes accelerate littoral drift (Kench, 2010). Technical understanding of the breakwater and site-specific information is necessary prior to breakwater design as it can have a significant impact on the coastline. Material size, slopes, crest width and elevation are important information required for breakwater design. Additionally, wave height, wave direction, structure slope, acceptance of risk, and material availability are also important key information required (McCue et al., 2012).

Breakwaters are widely used and have been one of the most common measures of coastal protection in the RoM because of the fragile nature and the unique geographic features of the islands (MHE, 2011b). Table 3-7 summarises the advantages as well as disadvantages of breakwaters in general.

Table 3-7 Advantages and disadvantages of Breakwaters (adapted from French (2001)).

Advantages	Disadvantages
• Help to reduce wave energy received at the coastline • Increase sedimentation and beach extension • Reduce coastal erosion • Reduce flood risk due to wave overtopping • Reduce sediment loss through rip cell activity • Help to form new reef ecosystem that helps to increase biodiversity	• In some cases BWs can modify longshore currents by wave deflection • Sediment retention resulted from BW can sometimes increase erosion elsewhere along the coast • Can be aesthetically intrusive • Expensive to build and repair • Possible scour problems through gaps in segmented breakwaters

3.5.1.1 Rock armour breakwater

Rock armour breakwaters are one of the most resilient yet flexible types of coastal protection measure. The structure is capable of withstanding to differential settlements and is 'time-tested and quite economical if rock armour is readily available' (USACE, 1981b). The stability of a rock armour breakwaters is often high because the wave energy can pass over the crest, providing the seaward slope of the armour layer to deal with lower wave forces (van der Meer et al., 2005). Additionally, the properties of material (armour weight and shape, underlayer size and shape, under-layer and core permeability), the foundation (toe support and detailing of the superstructure), and the hydraulic processes driven by wave action are some determinant factors of a stable breakwater (Ahrens, 1989). Figure 3-6 shows a rock armour breakwater under construction in one of the islands of the RoM.

Figure 3-6 A rock armour breakwater under construction in the RoM

Wave forces on the rock armours are normally high and act on individual structures. The interaction of wave with a rock armour breakwater creates a turbulent flow, particularly closer to the surface of the structure (Ahrens, 1989). These interactions increase wave energy on the structure that escalates toe scour (Neelamani & Sandhya, 2005).

Rock armour breakwaters are widely used around the world for the construction of artificial harbours and for coastal protection works (Neelamani & Vedagiri, 2002). It is becoming a popular method of coastal protection in the RoM. However, rock armours are not locally available in the RoM and the projects that use rock armours are limited to the amount of quota available to import from other countries (MHI, 2014).

Rock armour breakwaters are effective in any wave climate and can perform well in any depth of water (O'Neill Jr, 2000). Table 3-8 summarises the advantages and disadvantages of rock armour breakwater.

Table 3-8 Advantages and disadvantages of Rock Armour Breakwater

Advantages	Disadvantages
• Differential settlements does not necessarily fail the structure • Has the capacity to absorb and dissipate wave energy • Acts as a barrier to offshore sediment transport • Resilient to high energy conditions • Provides habitat for flora and fauna to colonise – it provides a useful reef habitat (French, 2001) • Provide sheltered harbour	• Does not solve the cause of erosion, modifies reef top wave and current process, fundamentally alter the nearshore coastal process regime, alter the natural coastline dynamics and it likely to promote island instability (Kench, 2010) • Material not locally available • Can be constructed in relatively shallow water depth • Aesthetically intrusive – not suggested for coastlines with scenic attractions due to the visually intrusive nature (French, 2001)

3.5.1.2 Tetrapod Breakwater

Tetrapods are four legged concrete structures intended to prevent coastal erosion, provide protection against waves in harbours, and also provide protection from currents and siltation (Hesse, 2017; Park et al., 2014). Tetrapods are a patented breakwater armour units of tetrahedron shape developed at the Laboratoire Dauphinois d'Hydraulique in Neyrpic, Grenoble, France (Hudson, 1959). Tetrapods are sometimes referred as rubble mound breakwaters (Hesse, 2017; Park et al., 2014). According to Hesse (2017), other forms of concrete units that followed tetrapods include Tibar (U.S., 1958), 'the Modified Cube (U.S., 1959), the Stabit (U.K., 1961), the Akmon and the Tripod (Netherlands, 1962), the Cob (U.K., 1969), the Dolos (South Africa, 1963), the Antifer Cube (France, 1973), the Seabee (Australia, 1978), the Shed (U.K., 1982), the Accropode (France, 1980), the Haro (Belgium, 1984), the Hollow Cube (Germany, 1991), the Core-Loc and the A-Jack (U.S., 1996 and 1998, respectively), the Diahitis (Ireland, 1998) and the Samoa Block (U.S., 2002)'. They are designed to dissipate wave energy by absorbing the waves rather than breaking the waves against them.

The interlocking arrangement and the weight of tetrapod structural units keep them stable in all weather conditions. Voids in between the randomly placed units allow strong waves to go around and pass through the structures making them dissipate wave energy on the way towards the coast.

Design parameters for tetrapods are hydraulic parameters (wave height, wave period, and number of waves) and structural parameters (crest height, nominal diameter of armour stone, density of placement, and density of concrete) (De Jong, 1996). A series of experiments conducted by De Jong (1996) found that variation of water depth did not impact much on the success of tetrapod breakwaters. Figure 3-7 shows a breakwater constructed using tetrapods at one of the industrial islands in the RoM, Kooddoo and Table 3-9 summarises the advantages and disadvantages of tetrapod breakwater.

Figure 3-7 A tetrapod breakwater at *Gaafu Alifu Kooddoo* port, the RoM

Table 3-9 Advantages and disadvantages of Tetrapod Breakwater

Advantages	Disadvantages
• Can withstand extreme weather conditions and adjust for differential settlements • Dissipate wave energy by absorbing it to the voids • Provide sheltered harbours and act as barriers to offshore sediment transport • Create new reef ecosystems and promote biodiversity	• Difficult or often risky to walk on the BW • Can alter the natural coastline dynamics • Can be aesthetically intrusive • Can be a navigational hazard • Can only be constructed in relatively shallow water depth

Tetrapods can become dislodged over time under strong wave environments. They are criticized as being risky for swimmers and aesthetically intrusive (Hesse, 2017). Tetrapods are less common compared to other breakwater types in the RoM. The main reasons are the limited space for controlled construction, and the difficulties in logistics and placement (MHI, 2014). However, majority of breakwaters around the capital, Male' are constructed using tetrapods. Tetrapods can form new reef ecosystem and increase biodiversity as they are proven to be good algal substrata (Watanuki & Yamamoto, 1990).

3.5.1.3 Sand-cement bag breakwater

Sand-cement bag or grouted sandbag breakwaters are constructed with hessian/gunny bags or geotextile bags filled with weak concrete or grout, that are stacked in interlocking arrangement (MTCC, 2014). Local engineers came up with the design of sand-cement bag breakwaters as an alternative to coral mound breakwaters, when coral mining was banned in the RoM (MHI, 2014).

Sand-cement bags are densely packed on a levelled sand bed that usually has a geotextile layer placed on the entire length. The bags are manually placed layer by layer. The bags in a single layer are arranged in a way that part of every other bag overlaps on the bag in front. The density of the top units and their tightly packed arrangement restrict the movement of individual units in the layer below them. Figures 3-8a and 3-8b show wave over topping, and the damages it caused respectively, in a sand cement bag breakwater. As the breakwater was placed on the reef edge, ocean waves break directly on the structures resulting wave overtopping that results unusual turbidity in the harbour basin.

Figure 3-8 A Sand-cement bag breakwater in *Raa Innamaadhoo* island, a) Wave breaking and overtopping, b) Bags dislodged after wave overtopping and wave breaking

The structural integrity of the breakwater 'depends on the individual bags remaining in place and intact' (USACE, 1981b). The low permeability of the sand-cement bags make the structures as wave reflecting that accelerates scour (McCue et al., 2012). Formation of voids between the bags make the structures less resilient to wave attack (Thorn & Roberts, 1981b). Sand-cement bag breakwaters have the tendency to collapse if a single unit is dislodged (MHE, 2011b). In some cases, where the low quality of grout make the breakwater to fail once the hessian bags rot away by wave exposure (Beca, 2010).

The practice is identified as a low initial cost - low skill measure that can rely on locally available materials (McCue et al., 2012). Table 3-10 summarises the advantages and disadvantages of sand-cement bag breakwater

Table 3-10 Advantages and disadvantages of Sand-Cement Bag Breakwater

Advantages	Disadvantages
• Materials are readily available • Light weight – easy to place even manually • The units are easy to reshape when grout is soft. Also the individual units hold their shape after the fabric deteriorates or is torn (USACE, 1981b). • Acts as a barrier to offshore sediment transport	• Low permeability of bags encourages higher wave reflection that results scour erosion • Alter the natural coastline dynamics and it likely to promote island instability • Bags are usually light weight – susceptible to displacement of individual units in moderate to high wave conditions • Can only be constructed in relatively shallow water depths • Aesthetically intrusive • Tendency to fail the whole structure if a single unit is dislodged • High maintenance is required

3.5.1.4 Geobags Breakwater

Geobag breakwater comprise high strength geotextile/geosynthetic fabric bags that are filled either with local sand or mortar (Korkut et al., 2007). Because of their simplicity in placement, construction, and their low impacts on the environment, geobags or geo-synthetic container/tube/mattress breakwaters are becoming a very popular method of coastal protection measure in many countries (Narayana Pillai & Verma, 1977; Neelamani & Vedagiri, 2002; Oh & Shin, 2006; Pilarczyk, 2017; Pilarczyk, 2003), however, the application is limited to resort islands and other low energy environments in the RoM (MTCC, 2014).

The lack of proper design criteria is identified as the main obstacle in geobag breakwater application. Although the designs were based on vague experiences in the past, increased popularity in geobag breakwater have led to research proper designs (Pilarczyk, 2017). Research identified that different shapes and sizes are attainable with geobags. While they can be shaped flat or elongated structures they can be placed stacked or as blankets. They help to dissipate wave energy transmitted to coastline by breaking waves further from coastline (Pilarczyk, 2017).

Geobags can be filled with dredged spoil directly from excavation (Figure 3-9), however, it is not advisable to fill the bags completely (Chu et al., 2012; Kim et al., 2013). Additionally, the foundation where the bags place should be smooth and preferably levelled. Geobags or tubes can be filled on land or in water (Pilarczyk, 2017).

Figure 3-9 Geobags filled with dredged spoil in Laamu Gamu Island

The ultraviolet rapidly degrades the fabrics of geobags, deteriorate them completely if placed in heavily exposed areas (USACE, 1981c). Exposed surface can be protected by plastering or spraying in-situ grout on exposed areas, preferably when the breakwater is settled (Chu et al., 2012). Geobags are practical in low to moderate wave conditions. The bags can be damaged by boat anchoring. Geo bags made out of nonwoven fleece needled material are durable, traps sediments and provide a habitat for biodiversity(Pilarczyk, 2017).

Geotubes are difficult to maintain lateral stability when stacked one on top of another (Chu et al., 2012). This can be solved by changing the shape and form of the geotextile used to mattress where the stability can be achieved by increased lateral dimension (Chu et al., 2012). Concrete blocks are sometimes placed on top of geobags to guard them against vandalism (Oberhagemann et al., 2006). Removal of bags either by vandalism or damage will reduce the stability of the structure thereby impacting the design reliability of such structures.

Geosynthetic material used in geobags are a cost-effective and can be used as an alternative to conventional breakwaters (MTCC, 2014). Additionally, they can be combined with conventional constructional material for durability (MTCC, 2014). Placement methods include barge mounted crane, split-hull hopper barge, and direct pumping of dredge spoil into bags. Table 3-11 summarises the advantages and disadvantages of geobags breakwater.

Table 3-11 Advantages and disadvantages of Geobag Breakwater

Advantages	Disadvantages
• Empty containers can be transported easily • Local sediments and concrete can be used to fill the bags or tubes • Can be converted easily to a range of different sizes • They are easily tailored to specific application • They can be filled by hydraulic pumping or other mechanical means • They can be implemented with lower initial costs and faster construction than other methods • Filled material is not subjected to erosion after placing • Quick construction	• They are not practical options for scour protection • Not suitable for deeper areas and high wave environments • Subject to vandalism • Bags will deteriorate under UV light

3.5.1.5 Caisson Breakwater

Caisson breakwaters are precast-prefabricated gravity retaining structures placed using mechanical means (Chu et al., 2012). Caissons breakwaters have widely been used in many parts of the world over the last 60 years (Dupray et al., 2010). They are ideal for breakwater construction in deeper waters (3 to 10m) and high energy conditions (USACE, 1984). However, the high wave reflection and wave impact because of the vertical frontage makes the units to slide or overturn in high wave environments (Dupray et al., 2010; PIANC, 2003; van der Meer et al., 2005). This can be minimized by using semi-circular shaped units on the top that makes the overturning moment smaller, the lateral wave force weaker, and reduced material compared to vertical box type caissons(Chu et al., 2012). Although the placement methodology is more challenging, sloping front caissons are more stable against sliding than vertical front caissons (Dupray et al., 2010).

The foundation must support the structure weight and the wave impact and withstand to scour. Rip-rap is usually placed along the base of caissons to stop scour erosion (USACE, 1984). Some of the failure mechanisms identified by PIANC (2003) are damages to rubble mound foundation, rubble mound protection and toe (scour).

A wide range of novel and combined approaches of caisson are becoming popular methods of breakwater construction. Cellular caissons (that allow better structural behaviour), perforated (that increase the energy absorbed by the structure), and suction caissons (that avoid the treatment of the seabed soil) are some of the popular caisson types (Chu et al., 2012; Dupray et al., 2010). Although prefabrication demands extensive resources, caisson breakwaters require less construction time and resources than other equivalent breakwaters (e.g. rubble mound) (Hutchinson et al., 2011). Figure 3-10 shows a caisson breakwater under construction.

Figure 3-10 Construction of a concrete caisson breakwater in an island

The height and weight of caissons breakwater should match the depth and wave energy of the water. Additionally, the weight must be proportional to the bearing capacity of the seabed to avoid settlement or failure of the structure (Chu et al., 2012). Table 3-12 summarises the advantages and disadvantages of caisson breakwater. Because of their bulky nature and the difficulty in transportation from a central location, the application of caisson breakwaters are very limited in the RoM (MTCC, 2014).

Table 3-12 Advantages and disadvantages of caisson breakwater

Advantages	Disadvantages
• Requires shorter time for on-site construction that reduces materials and construction staff on site • Perforated caissons increase the energy absorbed by the structure via the internal dissipating chamber • Cellular caissons allow better structural behaviour • Suction caissons do not require the seabed soil to be treated before installation	• Higher reflection and wave impacts due to vertical frontage may cause caisson units to slide on their base • The density of the caissons may cause settlement or bearing capacity problems • Repair and maintenance of the caisson wall is difficult • Heavy construction plants and equipment required for placement

3.5.1.6 Steel sheet piled Breakwater

In area where the surges and wave actions are severe and the risk of wall failure by scour erosion is high, steel sheet piles are used (Thorn & Roberts, 1981b). Steel 'sheet pile wall obtains its soil retaining function from the soil pressure, anchoring system, and the resistance of the wall against the bending moments and transverse forces' (CUR, 2005).

Most common types of piles used in the RoM are 'Z', 'U' or straight web sections. They are driven using vibratory hammers installed on cranes or long arm excavators and the sheet piles are connected by means of interlocks. Concrete capping beams are used to join the vertical elements together at the top. Pile breakwaters of Z and U sections are mostly constructed as anchored or braced pile walls. In anchored walls, main wall units are connected to another parallel line of sheet piles using tie bars (MTCC, 2014). These anchor walls provide additional support to the breakwater against seaward deflection (USACE, 1981c). Therefore, the double wall breakwaters in open water can hold the lateral earth pressure and the water pressure (Sawaguchi, 1974).

Steel sheet piled breakwaters are recommended for coastal areas where moderate wave distribution are permissible (Mani & Jayakumar, 1995; Sundar & Subbarao, 2003). Steel breakwaters create tranquillity on the lee of the structure providing safe manoeuvring and berthing of vessels (Sundar & Subbarao, 2003). If steel pipes are used instead of sheets, the number of piles needed for construction would be reduced (Mani &

Jayakumar, 1995). Figure 3-11 shows one typical steel sheet pile breakwater under construction in an island in the RoM.

Figure 3-11 Construction of a steel sheet pile breakwater in an island in RoM

Steel sheet piled breakwaters have a very high initial cost of construction and requires careful preconstruction procedures for durability and longevity (Sundar & Subbarao, 2003). Protection of steel especially plain carbon steel in salt water is relatively expensive and is difficult to maintain (USACE, 1981c). However, there are some of the islands in the RoM that have been protected with steel sheet pile breakwaters. Table 3-13 summarises the advantages and disadvantages of steel sheet piled breakwater.

Table 3-13 Advantages and disadvantages of Steel Sheet Piled Breakwater

Advantages	Disadvantages
• Relatively short construction time compared to other measures • No excavation required below existing beach surface level • Prevents loss of foundation material by wave scour and leaching from overtopping water or storm drainage beneath the wall	• Material delivery can take a long time • Pile-driving equipment required • Highly wave reflective – creates unusual current near piled wall • Potential to overload if the structure has been under-designed • Highly corrosive in salt water

3.5.2 Revetments

Revetments are protective sloping structures placed on an embankment or profiled beach fill material to protect scarp, embankment, or other amenities on the coastlines against coastal erosion (Leafe et al., 1998; SPM, 1984). Revetments structures absorb wave energy and help to reduce wave over-topping (Crossman et al., 2003; Gier et al., 2012).

The main difference between seawall and revetment is that ‘revetments rely on the land behind for structural support, whereas a seawall is self-supporting’ (Beca, 2010). Typical revetment structures consist of three layers: the sloping armour layer (provide protection against wave action), the filter layer (provide water to pass through the structure while preventing the underlying soil from being washed through the armour), and toe on profiles (prevents displacement of the seaward edge of the revetment) (USACE, 1995,2003).

Revetments are designed to withstand wind, wave and current flow attack (Escarameia, 1998). USACE (1981c) classified revetments into three classes, flexible, semi-rigid, or rigid. According to USACE (1981c) and O'Neill Jr (2000), flexible revetments can have their protective features unaffected even the structural arrangements disturbed. Semi-rigid revetments are less tolerant than flexible revetments to distortion (USACE, 1981c), and rigid revetments fail completely if distorted (O'Neill Jr, 2000).

Revetment structures dissipate wave energy more effectively than that of vertical seawalls. Revetments help to provide calmer harbours, reduce coastline erosion, and help to reduce flooding of low-lying areas by wave over-topping (Thorne et al., 1995). Additionally, well-designed revetments can reduce the impacts of storm surges effectively (van de Graaff et al., 1991).

A stable slope is required to ensure the effectiveness of any type of revetment applied (USACE, 1981c). The coastline or beach face is normally sloped for the revetment units to be laid evenly. In most cases, revetment units are placed on geotextile layer placed on the prepared slope. The most common material include sand cement bags, precast concrete blocks and rock armours. McCue et al. (2012) advised to construct the toe and crest of revetment to be constructed ‘landward of the limit of normal wave run-up to avoid scour problems, and about 1m above the limit of run-up during storms to avoid overtopping damage respectively’.

3.5.2.1 Rock armour revetments

Rock armour revetments are flexible structures that retain their protective qualities even if the structure is distorted, when differential settlement occurs, the toe of the revetment sinks (USACE, 1981c). Although, the revetments are considered flexible, Van Der Meer (1988) advised to allow only little displacement to rock revetment designs under severe conditions. Payne (1980) identified that loose formation of rocks generally settles in high energy conditions and suggested them to be mechanically fastened for better results.

Rock revetments constructed in the RoM are recent and no research has been conducted to find their suitability and efficiency to RoM coastlines. However, it is a common application worldwide and it is identified as a successful coastal protection measure (Bradbury et al., 1988). Rock revetments are identified as effective in most extreme wave climates (O'Neill Jr, 2000). The voids in the revetments can easily be filled with longshore sediments that in some cases help to create sandy coasts. Figures 3-12a and 3-12b show a revetment structure in an island and the same structure filled with sand and vegetation covering respectively.

Figure 3-12 A rock armour revetment constructed on the eastern coast of Gaafu Alifu Villingili a) after construction, and b) after it became covered with sand and vegetation.

Rock is sometimes preferred over other materials because of their natural appearance (Bradbury et al., 1988). Although rock armour breakwaters are a popular method of coastal protection in the RoM, rock revetments are less common. The main reason is the material not readily available in the country (MHI, 2014). Pilarczyk (1998) identified that critical failure mode (initiation of motion, deformation, rocking, abrasion), wave loading (max velocity, wave impact, climate), and strength (weight, friction, permeability of sublayer/core) are important aspects to consider in rock revetment design. Additionally, USACE (1981c) advised to use rocks of certain shapes (avoid using plate-like or cylinder-shaped pieces; stones should be angular and blocky, not rounded), provide additional layer of rubble at the toe, and locate the toe of the revetment 'at least three feet below the existing grade line to prevent undercutting'. (Scottish Natural Heritage, 2017)) also encouraged to extend the sloping face well below the normal beach level and suggested to set crest according to expected wave run-up levels. Table 3-14 summarises the advantages and disadvantages of rock armour revetment.

Table 3-14 Advantages and disadvantages of Rock Armour Revetment

Advantages	Disadvantages
• The fixed coastline allows developments up to that line and easy access to beach (Scottish Natural Heritage, 2017) • The flexibility of rock revetments allow rock units to settle into the base soil but continues to function with minor settlement damages • The rough surface of rock armours limits wave run-up and overtopping • Requires less onsite labour • Controls erosion	• Placement of rock armours generally requires heavy equipment • Aesthetically intrusive – not suggested for coastlines with scenic attractions or tourist usage due to the visually intrusive nature (French, 2001) • Face slopes increase the capacity to absorb wave energy and reduces the risk of scour erosion • Material not locally available • Complete disruption of natural beach-dune processes • Sometimes increase erosion further downstream • Decreases access to beach from upland areas (O'Neill Jr, 2000)

3.5.2.2 Sand-cement bags revetment

Construction material and methodology of sand-cement bag revetments is similar to that of sand-cement bag breakwaters except that breakwaters are placed offshore and require special attention in deeper water placement (MTCC, 2014). MHE (2011b) identified the sand-cement bag revetment is 'one of the key measures to promote and replicate across islands', which is very cost-effective compared to rock armours.

The critical failure mode (initiation of motion, deformation, sliding), wave loading (max velocity, seepage), and strength (weight, friction, permeability or sublayer/core) are important design aspects for sand-cement bag revetment construction (Pilarczyk, 1998).

Sand-cement bag revetments have the flexibility to be placed on any form of coastlines, thus, when buried on the coastline or beach profile, they form a final line of protection after the overlaying sediment have been eroded in high energy environment (Scottish Natural Heritage, 2017).

Although the structural integrity is lost in sand-cement bag breakwaters when a single bag is dislodged, the geotextile layer on the slope can hold the remaining bags of the revetment intact under low wave conditions (MTCC, 2014). Figure 3-13 shows a sand-cement bag revetment constructed at *Shaviyani Feevah* island coastline. When sand-cement bags were arranged on the beach profile by a coastal contractor, the island community have filled the top of the revetment with a sand-cement plaster layer (MTCC, 2014).

Figure 3-13 A sand-cement bag revetment covered with cement plaster at *Shaviyani Feevah* island in the RoM

The practive is identified as simple and cost-effective. The application appropriate for low to moderate energy coastlines (Scottish Natural Heritage, 2017) or to coastlines where resilient offshore measures are implemented offshore to combat strong waves actions (MHI, 2014). One of the most successful sand cement bag revetments is placed in the eastern coastline of Hulhumale' where littoral sedimentation enabled sand to be deposited on the revetment, totally covering the whole length in less than a year (MTCC, 2014). Table 3-15 summarises the advantages and disadvantages of sand-cement bags revetment.

Table 3-15 Advantages and disadvantages of Sand-Cement Bags Revetment

Advantages	Disadvantages
• Low cost, low skill approach using local material that are readily available • Light weight – easy to place even manually • The units are easy to reshape when grout is soft. Also the individual units hold their shape after the fabric deteriorates or is torn (USACE, 1981b) • Can take shape of any form of profile	• Bags subjected to vandalism and deterioration in high wave condition • Aesthetically intrusive • Low permeability of bags encourage higher wave reflection that results scour erosion • Alter the natural coastline dynamics and it likely to promote island instability • High maintenance is required • Susceptible to displacement of individual units in moderate to high wave conditions

3.5.2.3 Concrete revetments

Concrete revetments are generally prefabricated concrete interlocking blocks placed on a beach profile to fix the coastline in place. The resistance of these revetment depends on the weight of individual units (Gier et al., 2012). As the individual units in S-block revetments are interlocked to form a unified surface, displacement of a single unit will likely deteriorate or fail the whole structure (McCue et al., 2012). Figure 3-14 shows a precast concrete block revetment constructed at Shaviyani Funadhoo coastline.

Figure 3-14 A precast concrete block revetment constructed at *Shaviyani Funadhoo* island

McCue et al. (2012) identified that a crushed rock foundation topped by a geotextile layer reduces the risk of failure by hydraulic pressure beneath the revetment face. Gier et al. (2012) stressed that socio-economic and environmental demands, apart from other hydraulic stability requirements should be considered in revetment designs. Hydraulic engineering requirements identified by Gier et al. (2012) through various sources include resistance against; wave load due to wave impact, uplift due to wave run down, erosion of sub layers, liquefaction of subsoil; adaptability to local settlement; and maintenance of residual resistance after damage. Although the wave load due to wave impact is the most visual loading, it is not the most dangerous (Bezuijen et al., 1987). Vertical parapet walls (usually curved) are used on the crest to reduce over topping issues in areas where frequent wave attacks are anticipated (Scottish Natural Heritage, 2017).

The critical failure mode (lifting, dending, deformation, sliding), wave loading (overpressure, wave impact), and strength (thickness, friction, interlocking, permeability including sublayer/geotextile, cabling/pins) are important design aspects for sand cement bag revetment construction (Pilarczyk, 1998).

The research by Gier et al. (2012) claimed that the increase in stability of interlocking revetments were not considered in design guidelines before their study. The results of experiments conducted by Gier et al. (2012) identified that the stability in interlocking blocks are three times more than that of loose units.

A successful precast concrete (S-block) revetment was impemented on the western coastline of Addu linked islands. The severe erosion on the areas was stopped successfully with interlocking concrete blcoks finally enabling the beach to grow resulting a stable coastline (MTCC, 2014). Table 3-16 summarises the advantages and disadvantages of precast concrete blocks revetment.

Table 3-16 Advantages and disadvantages of Concrete Revetment

Advantages	Disadvantages
• Performance of single layer revetment is relatively good compared to other types of revetments (Van Gent et al., 1999) • Blocks are interlocked – prevents displacement of individual units in low to moderate wave conditions • Fix line of defence allows amenities and other developments closer to the coastline. • Low cost, low skill approach using local material that are readily available • Can take shape of any form of profile	• The smoother surface of the slope increases amount of wave overtopping and wave transmission • Low permeability of the blocks encourages higher wave reflection that results scour erosion • Aesthetically intrusive

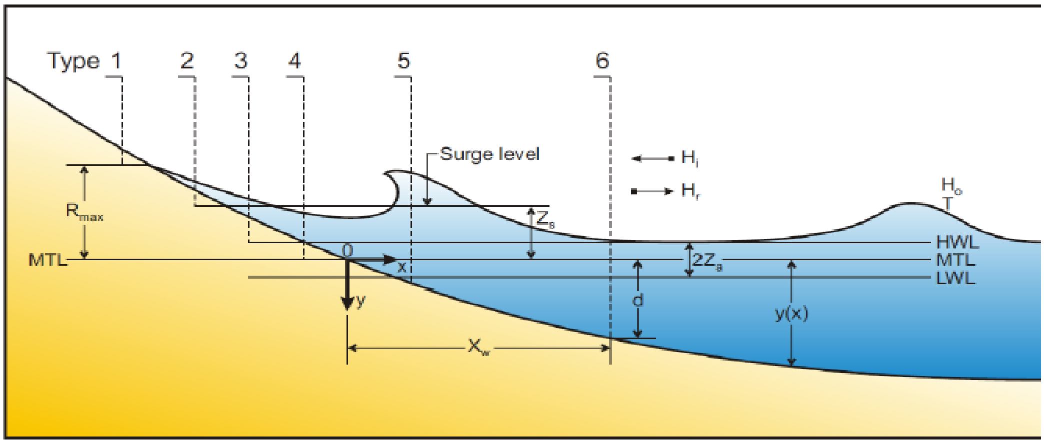
3.5.3 Seawalls

Seawalls are massive hard engineering structures with the key function of controlling coastal erosion subsequently alleviating wave overtopping and inundation (Sorensen, 2005; Thomas & Hall, 2015). Seawalls are generally constructed parallel to the coastlines (Ahrens, 1989; USACE, 2003). Sea walls can either be vertical (Scottish Natural Heritage, 2017) or sloping and they can be constructed from a wide range of materials including concrete, masonry, and sheet piles (Gornitz et al., 2001).

Once constructed, seawalls prevent coastline from further erosion that limits the coast from responding to environmental changes leading to process modification over time (French, 2001). Therefore, sea walls are generally recommended for locations where further coastline erosion result in excessive coastaline and hinetrland damage (Dean & Dalrymple, 2002).

For coastlines exposed to low to moderate wave actions, the decision of the type of seawall construction will be based upon the socio-economic and environmental considerations (Navy, 1991). Seawalls cannot be blamed for coastal erosion as identified that coastal erosion will occur regardless of whether there is a seawall or not. However, Beca (2010) agreed that seawalls can sometimes increase the rate of erosion due to wave reflection. To minimise these impacts of seawalls on coastlines, Pilarczyk (1998) encouraged to combine seawalls with other options.

The effectiveness of a seawall depends on the location of the seawall relative to the active coastline (WRL, 2013). Figure 3-15 shows seawalls classification using the Weggel (1988) system on an active beach profile. According to WRL (2013), locations of the seawall 'influences the extent to which the structure interacts with coastal processes such as waves and hazards such as erosion'.



Type 1: Landward of maximum level of runup during storms. The wall does not affect either hydraulic or sedimentation processes under any wave or water level conditions
Type 2: Above still water level of maximum storm surge and below the level of maximum runup. Exposed only to the runup of waves during storm events
Type 3: Above normal high water and below the still water level of storm surge. Base will be submerged during storms and during exceptionally high astronomical tides but will normally be above water
Type 4: Within the normal tide range; base is submerged at high water
Type 5: Seaward of mean low water; base is always submerged; subjected to breaking and broken waves
Type 6: So far seaward that incident waves do not break on or seaward (of the wall)

Figure 3-15 Weggel Seawall classification based on location of the wall. Classification reproduced and adapted from WRL (2013)

There have been a wide range of seawalls built in different parts of the RoM as coastal protection measures. The location of seawall can impact the coastlines considerably (Weggel, 1988). Table 3-17 summerises different types of seawalls used in the RoM and their descriptions adapted from Cummings et al. (2012).

Table 3-17 Seawall types used in the RoM. Descriptions adapted from Cummings et al., (2012)

Type	Description
Concrete armour units	Precast concrete units constructed in a wide range of shapes and sizes. Tetrapod seawalls have been used in some of the coastline in the RoM. These tetrapods in almost all case in the RoM are sloped as revetments with a concrete vertical wall supporting them on landward side so they are referred as revetments in this thesis. Additionally, gravity or tieback walls constructed of vertical blocks in the shape of 'L' are commonly used in the RoM
Sand cement bags	Sand-cement bag seawalls are constructed with hessian/gunny bags filled with grout and stacked in interlocking arrangement.
Steel Sheet piles	Typically steel driven sheet taken to adequate depths for geotechnical stability. Most common for deeper waters and ports.

Although, the initial costs of seawalls are high, requires expensive repair and maintenance, and affects adversely to beach aesthetics (Dias et al., 2003), they are the most commonly used coastal protection measure in the RoM (MHE, 2011b).

3.5.3.1 Precast concrete seawalls

Prefabricated L-shaped panels are the most commonly used material used in precast seawall construction in the RoM (MHI, 2014). These L-shaped reinforced panel are identified as durable, strong, and perform well throughout its design life (Broomfield, 2002). The concrete units/panels are prefabricated under controlled conditions and transported to sites when it achieves maximum strength. These vertical-face panels that are connected on the top by concrete beam or parapet walls and restrained to anchor piles can provide adequate seawalls in high wave conditions (Jachowski, 1965).

The retaining function of the precast units are generally obtained by the self weight and the weight of the soil lying above it. On the main part of the seaward face where settlement may be expected and where tide levels do not present great constructional difficulties, precast panels can be applied (Thorn & Roberts, 1981b).

Precast concrete seawalls are wave reflecting structures that create standing waves (the sum of incident and reflecting waves) infront of the seawall resulting more scour erosion (Jachowski, 1965). Additionally, the reflective nature of the seawall affect the cross-shore distribution of longshore currents infront of the wall (Jachowski, 1965). The main failure modes of seawalls according to WRL (2013) are : undermining, sliding, overturning, slip circle failure, loss of structural integrity, or erosion of the backfill. Structural failures can be prevented by consideraing the environmental impacts when designing structures. WRL (2013) identified that massive structures can mitigate the impacts of high wave loading, overtopping can be minimised with strutural modifications to crest, and undermining can be prevented by inproving scour material at the toe of the structure. To prevent wall failure by sediment seepage through joints, undrelying filter material can be used (Jachowski, 1965).

A range of concrete seawalls have been used in the RoM in the past (MHI, 2014). The poor performance or failure inmany of previous seawalls are mostly linked to the use of insufficient designs, poor construction techniques, the use of inadequate materials, the exposure of structures to severe conditions than anticipated or combination of two or more factors (Broomfield, 2002).

In L-shaped panels, the weight of the floor slab builds up shear stress in the sub soil which inturn provides an ‘opposing moment in relation to the horizontal soil pressure’ on the panel. Though the floor slabs are important for this reason, Thorn and Roberts (1981a) recommended that the designer must ensure that the wall to be constructed does not encourage erosion. Figure 3-16 shows a precast concrete sea wall under construction.

Figure 3-16 Placing of Seawall units at *Vaavu Felidhoo* Island

The popularity of precast concrete seawalls increased after tsunami 2004 (MHI, 2014). They are used in many islands of the RoM to protect hinterland assets and provide safer areas for vessels to alongside (MTCC, 2014). They are appropriate for exposed frontages with high value or cultural assets. Table 3-18 summarises the advantages and disadvantages of precast concrete seawalls.

Table 3-18 Advantages and disadvantages of Precast Concrete Seawalls

Advantages	Disadvantages
• Stiff structure not susceptible to potential structural stability problems as a result of differential settlement. • Cost-effective method of construction for vertical walls • Good detailing and quality control will limit annual maintenance and repair works required	• The main design issues: hydraulic loads and lateral forces on blocks • Risk of increased erosion along the coast and scour failure due to wave reflective properties • Heavy equipments and machinery required for construction • Reinforcements exposed will increase corrosion – making the structures less durable • Access of lifting equipment and underwater working are critical issues to address • Undermining – ‘the toe level drop below the

	footing of the wall, causing the wall to subside and collapse' • Sliding - in which the wall topples away from the retained profile • Slip circle failure - the entire embankment fails • Loss of structural integrity due to wave impact • Erosion of the backfill, caused by wave overtopping, high watertable levels, or leaching through the seawall

3.5.3.2 Steel Sheet Piles Seawalls

Steel sheet piles prevent wall failure by scour when the foreshore has been lowered by surges and wave action (Thorn & Roberts, 1981b). Sheet piled seawalls obtain their retaining properties from soil pressure, 'anchoring system, and the resistance sea wall against bending moments and transverse forces' (CUR, 2005). Sheet piled wall comprise of vertically-spanning piles interlocked and joined together at the top by the concrete capping beams. The primary function of piled wall is to prevent backfill from sliding. They are built in relatively sheltered areas, and are commonly used as berthing facilities (Navy, 1991; USACE, 1995). In the RoM, they are constructed for multi-purpose usage of the coastline, and are generally driven to the reef bed (MHE, 2011b).

The design and construction of steel sheet piled seawalls are very similar to that of breakwaters except the seawalls give protection to hinterland assets. They are driven using vibratory hammers installed on cranes or long arm excavators. Pile breakwaters of Z and U sections are mostly constructed as anchored or braced pile walls. In anchored walls, main wall units are connected to another parallel line of sheet piles using tie bars (MTCC, 2014). These anchor walls provide additional support to the breakwater against seaward deflection (USACE, 1981c). Figure 3-17 shows a steel sheet pile seawall under construction.

Figure 3-17 Construction works of steel sheet pile seawall at the coast of *Kaafu Hulhumale'*.

Cantilever seawalls are sometimes used for seawall construction in the RoM. The cantilever piled wall derive their structural stability through the depth of penetration of piles, hence are suitable for low to moderate wave conditions (USACE, 1981c). Cantilever seawalls are susceptible to failure due to toe scour (USACE, 1981c). Anchor piled wall obtain 'additional support against seaward deflection from anchors piles' on the landward side. These anchored walls are not recommended too close to buildings. Table 3-19 summarises the advantages and disadvantages of steel sheet piles seawalls.

Table 3-19 Advantages and disadvantages of Steel Sheet Pile Seawalls

Advantages	Disadvantages
• Relatively short construction time compared to other measures • No excavation required below existing beach surface level, removing problems associated with potential high groundwater levels during construction • Prevents loss of foundation material by wave scour and leaching from overtopping water or storm drainage beneath the wall	• Highly corrosive in salt water - cathodic protection system may be required • Potential to overload if the structure has been under-designed • Highly wave reflective – creates unusual current near piled wall • Pile-driving equipment required • Material delivery can take a long time

3.5.3.3 Sand cement bag Seawalls

Similar to sand cement bag breakwaters, sand-cement bag seawalls are constructed with hessian/gunny bags filled with grout and stacked in interlocking arrangement (MTCC, 2014). Sand-cement bag seawalls were first introduced as an alternative to coral mound seawalls (MHI, 2014). Sand-cement seawalls are one of the most common methods of seawall construction in the RoM until recently (MHI). These seawalls are identified as low initial cost measures that need high repair and maintenances in the RoM environment. Because of the frequent repairs coupled with the bitter experience of failing a significant number of seawalls in tsunami 2004, low maintenance and high durable measures started replacing sand-cement bag seawalls (MHI, 2014).

The densely packed bags are manually placed on a geotextile layer placed on the entire length a purpose made sand bed. The construction and placement methods of sand-cement bag seawalls are very similar to that of sand cement bag breakwaters. The bags are filled in-situ, laid in place before grout gets hardened, and readjusted to required shapes and tolerances (MTCC, 2014). Bags are arranged in horizontal layers in either zig-zag pattern or overlapping arrangement (MHI, 2014). Unlike breakwaters, when the required dimensions of seawalls are achieved, a plastering of about 20-25 mm is provided on all exposed surfaces together with a thin reinforced concrete slab on top (MTCC, 2014). Figure 3-18 shows a sand-cement bag seawall under construction.

Most common seawall failures are the bag displacement by wave action, and local scouring of beach levels (Scottish Natural Heritage, 2017). Other methods of seawall failures include hydrostatic pressure on the walls, subsidence near seawalls, use of heavy machinery and equipment on the wall, the poor quality of workmanship, and the low quality of grout used (Beca, 2010). Like other hard structural options, sand cement bag seawalls restrict the flow of natural dynamic material and change the longshore sediment transfer that result in localised erosion at their terminal ends (Scottish Natural Heritage, 2017).

Figure 3-18 Ongoing construction works of a sand-cement bags seawall at *Thaa Gaadhiffushi* Island

Sand cement bag constructions are cost-effective for a short term, requires low skills, and can be made with local materials (McCue et al., 2012). They can be applied on low to moderate energy coastlines and are adequate for temporary coastal protection measures (Scottish Natural Heritage, 2017). Table 3-20 summarises the advantages and disadvantages of sand-cement bags seawalls.

Table 3-20 Advantages and disadvantages of Sand-Cement Bag Seawalls

Advantages	Disadvantages
• Materials are readily available • Light weight – easy to place manually • The units are easy to reshape when grout is soft. Also the individual units hold their shape after the fabric deteriorates or is torn (USACE, 1981b)	• Low permeability of bags encourages higher wave reflection that results scour erosion • High maintenance is required • Bags are usually light weight – susceptible to displacement of individual units in moderate to high wave conditions • Aesthetically intrusive • Tendency to fail the whole structure if a single unit is dislodged • Alter the natural coastline dynamics and it likely to promote island instability • Can only be constructed in relatively shallow water depths

3.5.4 Gabions

Gabions are very common method of coastal protection in different parts of the world (Neelamani & Vedagiri, 2002; Oh & Shin, 2006); (Narayana Pillai & Verma, 1977) but not widely applied in the RoM. Gabions come as baskets, mattresses, and sacks that are filled with cobbles or crushed rock (Freeman & Fischenich, 2000; Scottish Natural Heritage, 2017). Gabion application in the RoM are generally seen as coral rocks or demolition rubbles enclosed in sacks and the application is seen mostly in resort islands (MHI, 2014).

Because the material used in gabions are flexible and porous, (Scottish Natural Heritage, 2017) identified that gabions can be used to reduce scour problems by absorbing wave energy. In areas where wave attack will be less severe, gabions can also be used to form groynes, revetments and breakwaters in less energy areas and they are easy to construct and the material are easily obtainable for most sites in the RoM (McCue et al., 2012). As they are enclosed and the fill material act as a group, they are not easily displaced (Narayana Pillai & Verma, 1977).

Gabions can be used as short term alternative to rock armours in countries like the RoM where rock armours are not locally available (Scottish Natural Heritage, 2017). As a coastal protection measures, gabions have earned a poor reputation as they are not sufficiently durable in regular strong wave environments. When designed, built and maintained correctly gabions can provide good service with minimal ecological or visual impact (Scottish Natural Heritage, 2017).

Well designed and constructed gabions are appropriate for protected or sheltered coasts subjected to low to moderate erosion where backshore assests are at risk (O'Neill Jr, 2000). Table 3-21 summarises the advantages and disadvantages of gabions.

Table 3-21 Advantages and disadvantages of Gabions

Advantages	Disadvantages
• Useful solution where armour rock is considered inappropriate or too costly • Materials are readily available • Porosity of material encourages wave energy absorption and coastline stability • Does not require heavy equipments • Gabions are flexible and does not impact on foundation settlements • Easy to reshape	• Light weight gabions are susceptible to in moderate to high wave conditions • The nets can be damaged by wave action • Require periodic inspections to identify weak areas and repair before damage occurs • Aesthetically intrusive • Tendency to fail the whole structure if part of the sack or net is damaged • High maintenance is required • Short term application only

3.5.5 Groynes

Groynes are generally narrow structures built perpendicular to the coast (O'Neill Jr, 2000) that are constructed from coastline to a sufficient water depth offshore in dynamic environments (Cummings et al., 2012). Groynes are measures used to stabilize coastline against erosion by trapping littoral drift and cross-shore sediments (Özölçer et al., 2006). It is a well-known method of building a beach if constructed in an area that has littoral drift parallel to the coast (Payne, 1980). They are one of the most traditional forms of coastal protection measures (Thorn & Roberts, 1981b) that slows down alongshore sediments, stabilizes up-drift side and correspondingly increasing erosion down-drift (Crossman et al., 2003; Dean & Dalrymple, 2004; WRL, 2013). Figure 3-19 shows erosion on one side while accretion on the other side of a groyne-jetty.

Figure 3-19 A precast groyne-jetty constructed at Laamu Gamu *Thundi Avah*

Rock armours and sheet piles are common material used to build groynes (Sorensen et al., 1984). In most cases, rock armours are preferred for exposed areas due to their resistance towards wave energy and their ability to wave absorption (USACE, 2003). Sheet pile groynes are not used in the RoM (MTCC, 2014). These permeable groynes allow sand to flow through the structure that retains sand without affecting down-drift material.

Groynes can be an ideal combination option to extend the design life of nourishment projects (EPA, 2014). The performance of groynes can be affected by their orientation, length, height, permeability, and spacing of the groynes (USACE, 1981b).

When the down-drift erosion is too high in an area, a groyne field (more than one groyne in a series) can be constructed and the area in between filled with sand (USACE, 1981b).

Groynes are sometimes combined with rock revetments to provide an effective erosion protection measure (Scottish Natural Heritage, 2017). They are practical for areas that have large amounts of sediments in the littoral system (O'Neill Jr, 2000). Figure 3-16 shows a precast concrete groyne constructed at Laamu Gamu island. Table 3-22 summarises the advantages and disadvantages of groynes.

Table 3-22 Advantages and disadvantages of Groynes

Advantages	Disadvantages
• Easy to build • long-term durability and ability to absorb some wave energy due to their semi-permeable nature (Scottish Natural Heritage, 2017) • Creates more area for recreation - normally acceptable to the public • Less expensive than seawalls or rock revetments • Littoral drift trapped by groynes can build up beach (O'Neill Jr, 2000)	• Submerged Aesthetically intrusive • Downdrift erosion may lead to pressure for other defence work (Scottish Natural Heritage, 2017) • Limited life, particularly where exposed to wave action • Visually intrusive • Alters beach dune processes as sand interchange is disrupted • Increased downdrift erosion

3.6 Chapter Summary

The common types of coastal protection measures used in the RoM identified through the literature review and the survey are discussed in Chapter 3. The Chapter also highlighted advantages and disadvantages of various coastal protection measures. While hard coastal protection measures are the most commonly used in the RoM, there is no single, fail-safe measure to address all the coastal protection issues that the islands are experiencing today. Combined approaches either with soft and hard measures or two or more hard measures are becoming popular in most parts of the RoM, and are proven to be effective by mitigating their individual drawbacks while merging their respective benefits. The next chapter looks into the policies of the RoM towards coastal protection and how the institutional and policy framework affect the decisions around the types of coastal protection measures installed in the islands.

4 POLICY TOWARDS COASTAL PROTECTION IN THE REPUBLIC OF MALDIVES

4.1 INTRODUCTION

Theoretical frameworks, policies, regulations, and the literature on coastal protection, particularly in the area of adaptive capacity, resilience, and climate adaptation and mitigation have emerged throughout the world over the last two decades (Schmidt et al., 2013). A number of developed and developing countries are in the process of implementing, monitoring and evaluating frameworks to examine changes in these countries' vulnerabilities to climate change (Dinshaw et al., 2014b). The RoM is one of the countries that remain strongly committed to environmental protection and sustainable development (MEE, 2015). Regardless of the numerous challenges and obstructions, the Government of the RoM maintains that the country is continuously working to strengthen national capacity as well as institutional and regulatory frameworks towards coastal protection (MEEW, 2007). The government supports the objectives of the United Nations Framework Convention on Climate Change (UNFCCC) and hence national policies are guided by the precautionary principles (MHE, 2001).

The RoM is inherently vulnerable to coastal erosion and other climate change related hazards due to its geophysical characteristics. A major cause of increased vulnerability to coastal erosion and other climate change related hazards is the absence of systematic protocols to address these hazards in the development planning processes, particularly in the coastal protection area. Consequently, the introduction of major structural modifications either via land reclamation projects or coastal protection projects without proper evaluation, decrease the natural resiliency as well as the local adaptive capacity of the islands to such hazards (UNDP, 2007). Even though there is now greater understanding of how coastal modifications can adversely impact islands and increase vulnerability to climate change, there are still a number of constraints in developing existing strategies. These constraints include gaps in the policy framework, weak inter-sectoral coordination, limited institutional and individual capacity for climate risk adaptation planning. Inadequate technical knowledge and know-how, as well as major financial constraints are also important (UNDP, 2010).

'Climate change adaptation policies, programmes, and projects need to affect change from international governance down to individual behaviour, and everything in between' (Bours et al., 2013). 'There is a growing recognition that decision makers often rely on intuitive thinking processes rather than undertaking a systematic analysis of options in a deliberative fashion. It is appropriate that climate change risk management strategies take into account both forms of thinking when considering policy choices where there is risk and uncertainty' (IPCC, 2014).

This chapter discusses the institutional framework of coastal protection in the RoM, presents and analyses relevant literature on the regulatory and policy frameworks of environmental protection, climate adaptation and mitigation that are related to coastal protection in the RoM.

4.2 INSTITUTIONAL FRAMEWORK OF COASTAL PROTECTION

With the introduction of advanced technological methods by using mechanical means in the early 1980s, the Ministry of Construction and Public Works (MCPW) became the sole agency to plan and execute coastal protection and related works in the RoM. The mandate of coastal protection was later transferred under the Ministry of Construction and Public Infrastructure (MCPI) after a major reorganisation of the ministries. With the change of government in December 2008, the responsibility was taken over by the Ministry of Housing, Transport and the Environment (MHTE). Subsequently, in 2013, the current institutional setup was established. In this setup, the Ministry of Housing and Infrastructure (MHI) formulates policies on all infrastructure projects including harbour construction and coastal protection while the Ministry of Environment and Energy (MEE) formulates policies on environmental protection and conservation including coastal erosion protection (MHE, 2011a). Other key stakeholder institutions in the coastal erosion protection include Environment Protection Agency (EPA) and Climate Change Department (CCD) of the MEE, Ministry of Finance and Treasury (MoFT), and Ministry of Tourism (MoT). Figure 4-1 shows the current institutional setup for coastal protection and related works in the RoM.

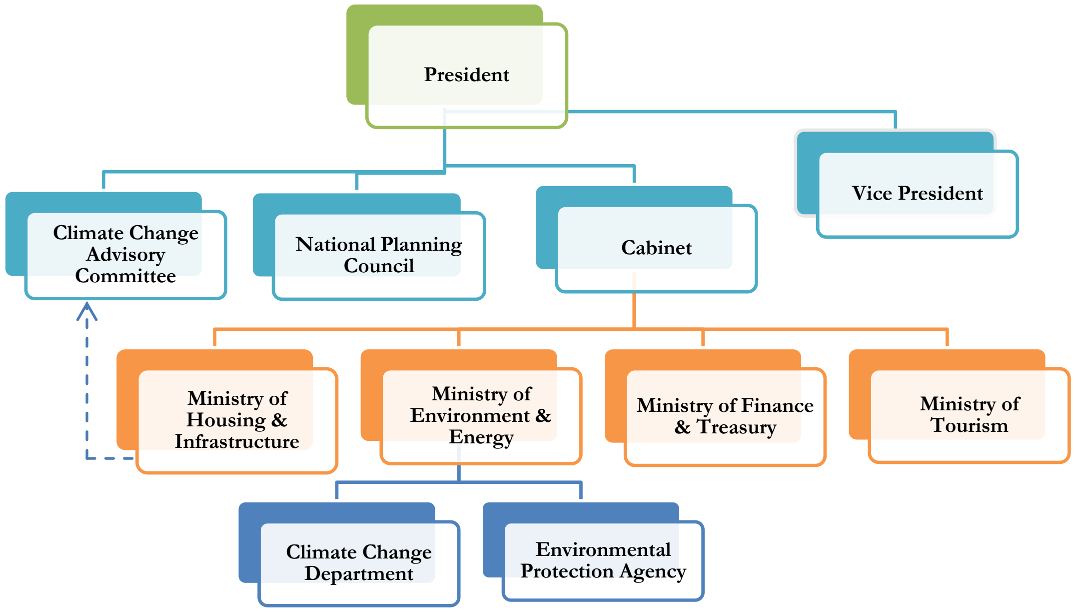


Figure 4-1 Institutional setup for coastal protection works in the RoM (MEE, 2014)

The CCD is the national focal point for UNFCCC and climate change issues in the RoM (MEE, 2016). The EPA is the regulatory authority for environmental protection in the RoM. The authority is also responsible to facilitate Environmental Impact Assessment (EIA) with proponents, asses the EIA reports, issue EIA decision statements, and monitor the construction and implementation stage of projects to confirm that EIA recommendations are complied. The National Planning Council (NPC) is the main body assessing and approving all development projects in the RoM including coastal protection projects. The members and resource persons of the NPC are decided by the Cabinet. For projects that are sensitive to climate change, the Climate Change Advisory Council's (CCAC) consent is required before a project is approved by the NPC.

The MEE, in consultation with other key stakeholder institutions, present an annual priority list of islands to the Cabinet for coastal protection funding. The priority list comprises islands that experience severe coastal erosion and are socio-economically vulnerable to coastal erosion and other hazards (MEE, 2014). Irrespective of the severity of coastal erosion, socio-economic condition, or location of the island, the final decision to develop remains solely as matter of Cabinet approval (MEE, 2014). EPA claims the Cabinets decision for project funding are inclined to political goodwill rather than need base (EPA, 2014).

The MoFT also plays a significant role in all government approved coastal protection projects, in determining project feasibility, project financing, and tendering. MoT is the regulatory authority for all tourism activities in the RoM including leasing islands for resort development, developing and maintaining standards for resort islands, formulation of guidelines and regulations for coastal protection in resort islands (EPA, 2014). The process of EIA evaluation and issue EIA decision statements was a responsibility of the EPA under EPPA 4/93. However, the government proposed amendments to the Maldives Tourism Act 2/99 and changed through parliament in 2015 that the evaluation and awarding of EIA for all resort islands to be a sole responsibility of the same institution that carryout the evaluation and awarding of bids for resort islands (ECOCARE, 2015). Ecocare, a non-governmental organisation released a statement stressing their concerns that the amendment would create an 'opportunity for corruption' (ECOCARE, 2015).

In the current institutional setup for coastal protection and related works in the RoM, the mandates are conflicting and, in some cases, not clear in defining coastal protection, infrastructure, harbour construction, and coastal erosion projects (EPA, 2014). For example, an island that is experiencing severe coastal erosion may be in need of coastal protection for the whole island or may require a harbour development project concurrently. There is a possibility that they may approach one ministry with all their concerns or waste additional resources in finding the right authority to report. Although project feasibility, project implementation and completion remain a sole responsibility of either MHI or MEE, there are no procedures or mechanisms established to collect data before, during or after projects and share it with other line ministries. Additionally, monitoring and evaluation after completion of projects are not mandated to any authorities currently.

Conflicting mandates between stakeholder institutions, lack of information sharing platforms, and the grey areas in the current institutional set-up would likely result in the inefficient use of resources, higher project costs and inappropriate implementation of measures. The current setup therefore requires a clear cut approach to define the types of work, allocate mandates to appropriate authorities, establish a cross-institutional mechanism in the data collection, monitoring, evaluation, and data sharing from project feasibility to a predefined date after completion of the project (MEE, 2014).

The current institutional setup does not support the active involvement of local stakeholders in the coastal protection decision making, especially in the initial stage of projects. The process of initial project works such as project selection, concept design, feasibility, tendering and project awarding involves a handful of professionals from the respective stakeholder institutions (MEE, 2014). Occasionally, during the implementation phase, key design decisions are changed after consultations with island representatives. These key decisions are highly dependent on the socio-political dynamics within each island. Thus, island elders retain knowledge of how these decision making processes occur and they form an important source of information about the impact of socio-political dynamics of an island on the decision (MHE, 2011b).

Efforts have been made to improve the cross-institutional contribution and stakeholder involvement in strengthening appropriate policies related to coastal protection in the RoM (EPA, 2014). With the ratification of the *Decentralization Act* and the *Local Council Election Act* in 2010, and the first ever local council election in February 2011, local councils were given the mandate of 'alleviating land erosion problems and maintain coastal protection structures around islands'. Every inhabited island in the RoM, under the *Decentralization Act,* is governed by an elected council with the mandate to prepare and execute city or island development plans in consultation with their local community. In the case of island councils, these plans need further approval from their respective atoll council before execution. Although more policies and regulations are coming into force, allowing cross-institutional collaboration and stakeholder contribution in projects the actual implementation of these tasks remain challenging due to systemic lack of institutional and human capacity. Part of this is to do with limited availability of technical expertise in the focal areas, while lack of clarity of roles and overlapping mandates between various line ministries and local authorities, especially in the newly decentralised local governance structure, also contribute to the challenges, and have led to establishment of mistrust and conflicts (UNDP, 2013).

4.3 EXISTING POLICIES & REGULATORY FRAMEWORKS

Local communities in the RoM have been dealing with coastal erosion in their islands since they occupied the islands (Kench, 2010). However, formulating policies towards coastal protection remains an area that needs due attention. Although some of the existing policies, strategies and regulations have varying degrees of relevance to coastal protection, and a few number of studies provided some form of support for policy makers, none of them provided a systematic approach to evaluate and select feasible coastal protection measures for the RoM.

In the absence of decision support frameworks on coastal protection, the activities on the coastlines are currently controlled or safeguarded by a handful of laws on the climate change and environment front, among which the *Environmental Protection and Preservation Act (EPPA)* is the most significant. Other regulations such as the *Environment*

Impact Assessment (Escarameia) and the *Regulation on the Protection and Conservation of Environment in the Tourism Industry* provide general guidance to protecting environment, but do not go into details of coastal protection and related activities. For planning, construction, monitoring and evaluation of coastal protection works, more stringent and better focused legislations are essential (EPA, 2014). Table 4-1 presents the coastal protection, climate change and environment related documents in the RoM.

Table 4-1 List of coastal protection, climate change and environment related documents in the RoM. Adapted from MEE (2015)

Legislations and Regulations	• Environment Protection and Preservation Act 4/1993 and its amendments 12/2014 • Environmental liabilities Regulation 2011/R-9 • Environmental Impact Assessment Regulation 2012/R-27 • Waste Management Regulation 2013/R-58 • Regulation on Dredging & Reclamation of Islands & Lagoons (No: 2013/R-15) • Regulation on Sand & Coral Mining (2000) • Maldives Land Law (No 1/2002) • The regulation on the Protection & Conservation of Environment in the Tourism Industry (2006)
National Communications/ Development Plans/Policies/ Strategies	• The Second National Communication of the Maldives to UNFCCC (2016) • National Environmental Action Plan (NEAP) (1990) • National Adaptation Program of Action (NAPA) (2007) • Maldives National Strategy for Sustainable development (2009) • Strategic National Action Plan for Disaster Risk reduction and Climate Change (2010)
Studies	• Survey of Climate Change Adaptation Measures in the Maldives (2011) • Detailed Island Risk Assessment in the Maldives (DIRAM) (2007) • Formulation of Guidelines for Climate Risk Resilient Coastal Protection in the Republic of Maldives (2012)

4.3.1 Environmental Protection & Preservation Act (Law No: 4/93 and amendments 12/2014)

The *Environmental Protection and Preservation Act* is the first environmental framework law of the RoM and became effective in March 1993. The law mainly emphasises the protection and preservation of the natural resources in the RoM. While the Act does not specify climate change or any other issues specific to coastal protection, it does provide the government with the ability to terminate any projects that are deemed to have an undesirable impact on the environment. However, some of the main articles: Article 4 - protected areas and natural reserves, Article 5 - environmental impact assessments, and Article 7 - waste disposal, provide guidance for coastal activities that may be detrimental to coastlines. Additionally, the section on '*Penalties for breaking the law, damaging the environment and compensation claims'* would help prevent damaging activities being carried out at the coastlines. MEE is aiming to include coastal protection more comprehensively in the EPPA together with a procedure of improving the legal and administrative co-ordination between various stakeholders to integrate environmental considerations into socio-economic development of the country (MEE, 2014; MHI, 2014).

4.3.2 Environmental Liabilities Regulation (No: 2011/R-9)

The '*Environmental Liabilities Regulation'* aims to control or prevent activities that violate the EPPA of the RoM. Actions that are detrimental to the environment are penalised in the regulation. It sets the mechanisms to categorise various types of environmental liabilities and grants the power of claiming compensation for the actions that breach EPPA to the government. The regulation can be an effective tool to control the type and scale of activities being carried out at the coastlines.

4.3.3 Environmental Impact Assessment Regulation (2012/R-27)

Under the *Environmental Impacts Assessments (EIA) Regulation,* EIAs are mandatory only for the projects that are qualified under the screening procedure issues by MEE. Projects selected under the screening procedure are required to carry out a scope of works decided by MEE, EPA, and other stakeholders from relevant government agencies.

In the first chapter of the Regulations, introduction of the regulation and the objectives of are described. The second chapter highlights on project planning. Third chapter describes the procedure in application and implementation of EIA process. Some key attributes of this chapter include: application for EIA, screening stage, initial EIA, environmental management plan, scope of works, EIA report, and EIA decision.

Fourth chapter highlights on the EIA decision statement. It describes the components of the decision statement and grievance procedure if EIA was rejected. Selection of EIA consultants and penalties are described in chapter five and chapter six respectively. Chapters seven and eight describe the power and impunities of the regulating staff and authorities and licences to the in the implementation of the regulation. The last chapter provides definitions on some of the key terms used in the regulation.

It is interesting to note that some of the checks and balances included in the first EIA regulation (2007) such as the involvement of public stakeholders in key stages of EIA process were removed from the new EIA regulation (2012/R-27) and regulatory authorities are given excessive powers. Some key attributes of chapter one in the 2007 regulation were: incorporating stakeholders' concerns; identifying stakeholders (concerned and affected); methods to incorporate community perceptions, and the use of stakeholder related data in the decision making. Apart from EIA, the repealed regulation covered coastal zone and marine environmental protection. It imposed MEE to formulate guidelines on environmental conservation and also to prepare a State of the Environment (SoE) report on coastal and marine environment in consultation with other relevant ministries every three years. It stressed that the SoE report should include an inventory of harbours, dredging activities, reclamation, coastal protection measures, waste disposal sites and information on other coastal infrastructures.

There are no stringent guidelines to follow for coastal developments associated with locally inhabited islands' in the EIA regulations. Although setbacks for 'no development buffer zone' need to be allocated based on the overarching standard of the Cairo Principle, there are no specifics provided to delineate such spaces (UNEP-GPA). Contrary to the official EIA written process, in its actual implementation, the public is only consulted after the feasibilities, designs and scopes of the projects are finalised (Niyaz & Storey, 2011).

4.3.4 Waste Management Regulation (No: 2013/R-58)

The *Waste Management Regulation of the Maldives* was enacted based on Article Twenty-two of the Constitution of the RoM and under powers vested in the MEE under the Article Three of the *EPPA* in relation to Article Seven and Eight of the same Act. The regulation emphasises prevention of pollution via responsible waste management practices. There are no specific issues identified regarding coastal protection in the regulation. However, in Clause 11, the regulation prohibits waste disposal in the protected areas under *EPPA*, wetlands, lagoons, reefs, sand banks, beaches, coastline, and harbours. It is expected that 'Penalties upon noncompliance and breach of the regulation' stated in *Clause Thirty-four (Noonu)* would help to prevent damaging acts being carried out at the coastlines. However, vesting the power in the central government without predefined terms on the types of penalties and the weights of compensation may lead to corruption and abuse of power.

4.3.5 Regulation on Dredging & Reclamation of Islands & Lagoons (No: 2013/R-15)

The *Regulation on Dredging and Reclamation of Islands and Lagoons in the Maldives* was enacted based on Article Twenty-two of the Constitution of the RoM and under powers vested in the MEE under Article Three of the *EPPA* in relation to mitigate or reduce losses due to dredging and reclamation in the RoM. The regulation puts emphasis mainly on carrying out dredging and reclamation activities in the lagoons and islands in the RoM. Key objectives of the regulation stipulated in *Article Three* of the regulation are mitigation and reduction of losses due to dredging and reclamation activities.

According to the regulation, permission to dredge or reclaim can be granted upon submitting a work procedure and land use plan to the implementing agency, the EPA. It also states 'dredging and reclamation may be permitted in the inhabited islands if the projects were intended to improve socio economic activities in the islands'. Main themes include: 'conditions for granting permission to dredge and reclaim in the Maldives'; 'reclamation for erosion protection'; 'standards to be used in dredging and reclamation'; 'protected areas for dredging and reclamation'; 'ways of treating dredging spoil'; 'allowable dredging and reclamation volumes/sizes'; 'changes to original shape of the islands due to reclamation'; and, 'mitigation activities that can be carried out to reduce losses to natural island formation'.

Additionally, the regulation underlines 'compensation claims for breaking the law', and, 'amendments to the regulation. Although it touched on a broad range of themes, the clauses are very brief and technical composition is ambiguous; hence a lack of specific issues relating to different coastal protection techniques.

4.3.6 Regulation on Sand & Coral Mining (2000)

In 1992, preliminary regulations were introduced to combat uncontrolled mining activities. The *Regulation on Sand and Coral Mining* put controls on sand and coral mining from all islands and bird nesting sand bars. Sand and coral mining from beaches of any island whether inhabited or uninhabited is banned for protection of the islands. A survey conducted in the islands reveals the primary purpose of sand and coral stone mining is for building construction since imported sand and aggregates are expensive for the islanders, while local sands and coral stones are free and readily available. Obtaining a license from relevant local authorities is one of the control measures set forth in the regulation to prevent sand and coral mining from sensitive areas.

4.3.7 Maldives Land Law (No 1/2002)

The Maldives Land Law is a framework law for allocating land for urban use either private or public use. The President is empowered to lay down the policies concerning the land of Maldives through consultation with the Cabinet. Although, broad categories of land use for urban, economic, social and environmental protection are defined, there is no clear definition of land in the law. It appears the existing definition is based on the terrestrial component of the island. The draft Land law 2008 does provide a definition of land as in the following:

> *'land' means the surface of the earth of an island as it is at low tide and the earth below the surface and all substances, other than oil and precious stones, forming part of or below the surface, things naturally growing on the land (but not trees and things planted by human agency on the land) and the airspace above the land up to a height reasonably necessary for the effective enjoyment and use of the land and includes:*
>
> *a) land reclaimed from the sea by human agency;*
> *b) the accession of land to an island by natural means; and*
> *c) land temporarily covered by water as a result of a natural disaster or human agency*

With the introduction of decentralisation Act in 2010, local councils were empowered to allocate lands that fall in their local zones for commercial and other economic and social benefits. However, with the request of the Government of the RoM, the parliament voted to revoke the power from local councils and reinstate it to the Heads of State in 2015.

4.3.8 Regulation on the Protection & Conservation of Environment in the Tourism Industry (2006)

The *Regulation on the Protection and Conservation of Environment in the Tourism Industry* was enacted based on Law No. 2/99 (Maldives Tourism Act). The regulation stipulates that permission from the Tourism Ministry shall be obtained prior to carrying out activities such as dredging the lagoon and reclamation of land, construction on the beach and lagoon, beach enhancement by pumping sand, construction of breakwater, construction of sea wall, revetment or groyne, and dredging of lagoon or reef for safe access.

Penalties for breaching the regulation is stipulated in Chapter Eight of the regulation. It states that 'If any provision of this regulation is contravened by any tourist resort, picnic island, marina, hotel, guest house, or tourist vessel, shall be guilty of an offence, and shall be liable to a fine, taking into consideration the seriousness of the non-compliance, between MVR1,000 and MVR10,000 in the first instance. Parties repeatedly in non-compliance shall be liable to a fine between MVR50,000 and MVR100,000. If non-compliance of a provision occurs more than once, the Ministry has the power to revoke the license.

4.4 OTHER RELEVANT DOCUMENTS

4.4.1 The Second National Communication of the Maldives to UNFCCC (2016)

The second national communication (SNC) of the Maldives to the United Nations Framework Convention on Climate Change (UNFCCC) is a country report submitted to UNFCCC in accordance with the guidelines set by the UNFCCC. In addition to the information on the progress made since the first national communication to the UNFCCC, the SNC highlights the significant vulnerabilities of the RoM and the efforts of adaptation and mitigation measures it adopts to overcome the challenges. Major components of the SNC include: National circumstances; climate projection; natural disasters and extreme events; mitigation measures; vulnerability to climate change; and, adaptation measures. The report also provides future plans and underlines the possibilities of integrating 'climate change into sustainable development goals' (MEE, 2016).

4.4.2 National Environnemental Action Plan (NEAP) - 1990

The first National Environmental Action Plan (NEAP) was published by the United Nations Environment Programme (UNEP). It recommended a number of policy responses, including the importance of an EIA mechanism (Niyaz & Storey, 2011). The most recent NEAP (2009-2013) supports the identified adaptation and mitigation goals, hence focuses more on the 'development of resilient islands' and 'protecting coral reefs' (MHE, 2010).

4.4.3 National Adaptation Program of Action (NAPA) 2007

The National Adaptation Program of Action (NAPA) was formulated to communicate the immediate and urgent adaptation needs as stipulated under the UNFCCC Decision 28/cp.7. Major climate change related factors that include vulnerability in small island national context are: sea level rise, extreme weather, changes to precipitation patterns, increasing temperature and access to resources. NAPA outlines 'adaptation measures for the short, medium and long term and formulated into 12 projects in 8 priority sectors' (MHE, 2010).

4.4.4 Maldives National Strategy for Sustainable Development (2009)

The Maldives National Strategy for Sustainable Development was published by the government of the RoM in conjunction with United Nations Education Program (UNEP). Several goals relating to climate change have been identified in the policy. However, goal number one only specifies development targets related to coastal protection. Goal 'One' – Adapt to climate change:

- Build coastal defences for Malé International Airport and *Seenu Gan* International Airport
- Develop coastal defences around ten selected islands
- Train forty coastal engineers

4.4.5 Strategic National Action Plan for Disaster Risk Reduction and Climate Change (2010)

The Strategic National Action Plan (SNAP) outlines the possible impacts from climate change vulnerabilities and other hazards (including further tsunamis, sea level rise, and coastal erosion). Four strategic areas of action were identified to minimise risks from disasters and to help the RoM adapt to climate change. They are: 1) Enabling environment for good governance, 2) Empowered and capable communities, 3) Resilient communities with access to technology, knowledge and other resources, and 4) Risk-sensitive regional and local development. Various activities have been listed in each area.

4.4.6 Survey of Climate Change Adaptation Measures in the Maldives (2011)

The purpose of the study was to provide baseline information on climate change mitigation measures to address coastal erosion protection in the RoM. Apart from a thorough compilation of various adaptation measures to combat coastal erosion in the RoM, it also analysed the relative effectiveness and cost implications of the measures. In addition, it identified 'the potential for implementation of 'soft' adaptation measures and the major barriers, constraints and opportunities at the island level' (MHE, 2011b).

4.4.7 Detailed Island Risk Assessment in the Maldives (DIRAM) (2007)

Detailed island risk assessment in the Maldives (DIRAM) is a technical study financed by UNDP and the government of the RoM initiated after the damage caused to islands and infrastructure by the tsunami 2004. The overall objective of the study was to assess the levels of the islands' exposure to different natural hazards. The study classified natural hazards prevailing in the RoM into four categories: geological, meteorological, hydrological, and climate change related hazards.

DIRAM study concluded the net benefit of coastal protection as negative, hence recommended the need for further investigation on the costs and benefits of these investments. However, DIRAM considered that any island could be made safer with the application of appropriate coastal protection measures. It is also optimistic that engineering solutions could control the impact of hazards for existing events that are facing the RoM. The reason for the negative net benefit is possibly due to the lack of decision support frameworks in the country to evaluate appropriate measures, or the lack of coastal protection measures specifically designed for the coral reef environment to combat the hazards as the current measures are mostly adapted from other environments. It also supports the assumption that engineering solutions are to be designed to withstand a predicted severe intensity event, if not a maximum predicted event specific to the island under consideration.

DIRAM study is identified as one of the most comprehensive studies conducted to evaluate multi-hazards data in the RoM (EPA, 2014). The set of multi-hazard data on DIRAM studies (except the coastal erosion data) are used in this framework as it is the only available data set covering multi-hazards data for the islands selected for this study. However, as the detailed data sets for the study could not be obtained for this research, the relevant data has been estimated from the maps and figures presented in the published report.

4.4.8 Formulation of Guidelines for Climate Risk Resilient Coastal Protection in the Republic of the Maldives

The guideline on climate risk resilient coastal protection in the RoM was drafted in 2012. This draft is yet to be finalised. The draft guideline addresses Engineering aspects of coastal protection projects and presents recommendations to improve the integration of climate change impact and resilience into current EIA processes. It does not provide a framework for selecting appropriate measures for the policies identified, but provides guidance on designing different coastal protection measures once a measure has been selected. (McCue et al., 2012).

4.5 Chapter Summary

This chapter discussed the institutional setup, analysed and presented the existing regulatory framework and policies relevant to coastal protection works in the country. Frequent changes to the mandates between government institutions, conflicting mandates and the lack of clarity in some of the mandates have been observed. There is no provision in the institutional framework to include local stakeholders in the coastal protection decision making, especially in the initial stage. A political body within the central government decides which island should get funding for coastal protection although a priority list based on the severity of coastal erosion and socio-economic situation is presented to the Cabinet annually. These politicised decisions hinder projects from being carried out at the islands that urgently need coastal protection. The weak institutional set up has resulted in ineffienient use of resources, higher costs, and inappropriate implementation of coastal protection measures.

Even though more regulations and policies are coming to force, encouraging cross-institutional collaboration and stakeholder contribution in projects, the actual implementation remain challenging due to systemic lack of institutional and human capacity. Part of this is to do with limited availability of technical expertise in the focal areas, while lack of clarity of roles and overlapping mandates between various line ministries and local authorities, especially in the newly decentralised local governance structure, also contribute to the challenges, and have led to establishment of mistrust and conflicts. Recent amendments to some of the existing regulations show the decreasing transparency and accountability to the public. The amendments to EIA regulation and the Tourism Act would open opportunities for corruption and abuse of power.

Although some of the existing legislations and policies have varying degrees of relevance to coastal protection, and a few studies provided some form of support for policy makers, none of them provided a systematic approach to evaluate and select feasible coastal protection measures for the RoM. Additionally, the existing regulatory and policy frameworks are insufficient in monitoring and evaluating performance of implemented measures on the coastlines.

In the next chapter, the Public Perceptions survey of local stakeholders further highlights these gaps in institutional, regulatory and policy framework and reveals the impact it has on decision making and stakeholder satisfaction at a local level.

5 PUBLIC PERCEPTION OF COASTAL PROTECTION WORKS IN THE REPUBLIC OF MALDIVES

5.1 INTRODUCTION

Coastlines are naturally dynamic and varied, with rapid changes in the coastal position resulting from wind, wave attack, changing sediment supply, and local factors including human intervention (Koutrakis et al., 2010; Prasetya, 2006). Coastal erosion is a natural process, but accelerated coastal erosion is becoming an everyday issue posing potential threats to livelihoods in the RoM (MEE, 2014). How to address coastal erosion and SLR is a challenge for the RoM where the islands are generally small in size, the population scattered in hundreds of geographically dispersed islands, and hence, all the residents perfectly fit into the category of coastal communities.

On a global scale, traditional agency decision-making in coastal protection has generally moved towards processes that involve stakeholders and acknowledge the importance of public attitudes, perceptions, beliefs, and knowledge. Although there is no universally effective way to incorporate stakeholders, researchers and practitioners generally agree that stakeholder participation is important and has many benefits (NOAA, 2007).

Alleviating the risks associated with coastal erosion and SLR in practice, is largely a local endeavour. Hence, the impacts will be directly attributable, and thus may be more effectively addressed, if local stakeholders are involved in the decision-making process for coastal protection works, as well as its implementation. Local stakeholder opinion of coastal degradation has rarely been systematically considered in the RoM in coastal protection decision making. Moreover, there is no information or monitoring system that provides feedback to the decision makers at central level, regarding island level coastal degradation problems, its context, seasonal variations, or the impact of past coastal protection measures. In such a context, the community's views and preferences on issues related to their coastlines, the causes that trigger coastal degradation, and their knowledge on impacts and implications of introducing different protection measures on their coastlines are crucial pieces of information that could facilitate decision makers in evaluating and selecting appropriate measures for effective coastal protection in the RoM.

This chapter presents and discusses the results of a survey conducted in ten inhabited islands across the country. The general aim of the survey was to understand local stakeholders' awareness of different coastal protection practices and decision-making processes, and what impacts there would be to the current mechanism if the level of local stakeholder contribution is increased in the formulation of strategies and decision making for coastal protection works. The objectives were to identify and investigate:

- the locals' awareness of and interaction with different coastal protection measures, coastal hazards, and coastal erosion,
- their understanding of the management and protection of local coastlines,
- what the communities value about their coastlines, and their current contribution in coastal protection decision making

5.2 SURVEY METHODOLOGY

5.2.1 Questionnaire Development

To achieve the stated objectives, a survey tool (Appendix B) was developed to gather information from the local stakeholders including the local residents and local government officials. Questionnaires used previously for such surveys were studied and structure of Becker (2007) and WRC (2011) was adapted in the questionnaire development. Expert opinion was sought from technical staff of Maldives Transport and Contracting Company plc (MTCC), the pioneer and the biggest coastal protection contractor in the RoM, and relevant government ministries to check if the questions covered research scope, goals and objectives of the research fully. Additionally, since the original survey was developed in English, and then had to be translated into the local language Dhivehi, for ease of implementation, these experts also assisted in checking the questionnaire for coherence, terminology, consistency and accuracy of translation.

The survey questions covered the following areas:

- Demographic characteristics of survey locations,
- Management and protection of coasts: roles and responsibilities of different stakeholders,
- Public knowledge on different coastal protection measures,
- Valued attributes of coasts to public,
- Coastal hazards and risks, and
- Local stakeholder contribution in the decision making.

5.2.2 Survey Island Selection

The climate in the RoM is generally warm and humid, typical of the tropics and characterized by the monsoons of Indian Ocean. The RoM observes two monsoon seasons: the North-East Monsoon (NEM) *'Iruvai'* from January to March (dry period) and the South-West Monsson (SWM) *'Hulhangu'* from May to November (rainy period). Monsoon wind reversal significantly affects weather patterns. Strong winds are associated with the *Hulhangu* season. Gales are uncommon and cyclones are very rare in the RoM. Stormy weather is more frequent from May to July. The average temperature ranges between 25°C to 30°C and relative humidity varies from 73 to 85 percent. Significant variation is observed in the climate between the northern and the southern atolls with greater extremes of temperature being recorded in the southern atolls. Currents tend to be monsoonal in origin, generally setting West during the NEM and East during the SWM. During the transition months, the currents are variable. Monsson winds are generally the driving force behind the flow of ocean currents through channels between atolls. The tropical cyclone risk to the islands of the RoM are considered low, however, the islands in the north of the country have been affected by weak cyclones.

Even though the general climate of the RoM is similar across the country, the local climates in different regions and islands differ depending on the location within country, within the atoll and island morphology. Different types of natural hazards affect the islands differently depending on these factors. For instance, cyclone hazard risk is higher in the northern atolls and lower in the southern ones, while earthquake risk is higher in the southern atolls than the northern. On the other hand, risk of swell waves is higher in the western islands while tsunami risk is higher in the eastern ones. Even within these general risk profiles, islands that are protected inside the atolls by other islands have a lower risk from some hazards, while other islands are more vulnerable due to their elevation or lack of vegetation.

Due to these differences in local climactic conditions, which impact the coastline changes to the islands, survey islands were selected with consideration to a range of factors. Ten inhabited islands across the RoM (Figure 5-1) were selected based on their development potential highlighted in the UNDP (2007) study. UNDP (2007) also identified that these islands 'are currently the targeted growth nodes in their respective regions in terms of development plans and population movement'. Most of these islands form part of the government's strategic agenda to make population consolidation centres across the country. Additionally, these islands together almost comprehensively cover all the major coastal protection systems in the country (Table 3-2). Furthermore, the differing geographic locations, varying sizes and orientations of these islands, in addition to the previous factors should contribute to the robustness of the data collected.

Figure 5-1 Map showing survey locations across the Maldives

5.2.3 Survey Implementation

Two methods of implementing the questionnaire, field visits and postal survey, were considered. Postal surveys were cheaper, but there were unacceptable drawbacks such as the unreliability and extremely slow speed of rural post services, confusions that may arise due to the absence of an interviewer to clarify the technical terms, and low response rates to postal surveys. Field trips required expensive travel to survey islands, but had the advantage of the researcher being able to interact with participants and closely monitor the interviews, collect information from field visits, and gather information from key informants about general views, perceptions, and local knowledge. Hence, field visits were chosen as the medium for the questionnaire implementation.

In addition to the questionnaire, a focus group discussion was also conducted with 'key Informants' in each surveyed island. The purpose of these focus group discussion was to collect information about macro level coastal protection issues and gauge the level of awareness of coastal protection policy, current and historical changes to their local coastlines caused by both modifications and natural phenomena. These discussions also helped to identify key sites for field visits, such as sites of accretion or erosion and sites that are vulnerable to natural hazards.

As a first step, island councils were requested in writing to identify between 50-70 participants from the local community of each island to participate in the survey. For the questionnaire survey, 30 participants were selected randomly from this list. Among those 50-70 participants originally identified, councils were also requested to further identify a small group of people, especially elderly residents who have knowledge of the coastal protection works, historical changes and modifications to local coastlines, and who also have involved or taken part in any surveys, discussions or decision-making exercises related to coastal protection works. These latter sub group that was identified formed the 'key informants'. In a small number of cases, a stakeholder could be both a survey participant as well as a key informant. This did not seem to create any significant distortions in the data or information gathered, since the information gathered in the questionnaires was different to the macro-level discussions held in the focus group discussion.

Field trips were conducted in person, by the researcher, to all the ten islands to carry out the surveys. On arrival to each island, local council members were briefed on the survey and tasks involved. Each council assigned one or two members from the council to assist the researcher in meeting the survey participants. Surveys were conducted individually by the researcher.

Focus group discussion arrangements were set up and key informants were invited through the councils. In most cases the workshops were held in the council secretariat hall, local school hall or a similar place. The researcher presented key findings of the proposal as a slideshow and requested the respondents to contribute to the study by asking relevant questions. Researcher took notes of key discussion points.

Important information relevant to key decisions made on coastal protection structures and other recorded information on the coastline changes and erosion and accretion in the islands, was sought from local council offices. Historical event records, base maps and land use plans were also obtained from various authorities in the RoM. Maps and plans were used to record information gathered during field visits.

Apart from some delays due to stormy weather, most field visits were conducted with minimal problems. However, due to the politically sensitive climate prevalent at the time the field studies were conducted, and the common perception that coastal protection projects are politically sensitive decisions, some survey participants chose not to engage in discussions relating to these projects and thus chose to withdraw from the interviews. In cases where participants dropped out, replacements were chosen from the master list until 30 interviews could be conducted. In a limited number of cases, a survey or workshop participant who was a local government representative would refuse to discuss any possible amendments to existing policy or the problems with the existing decision-making process. Nevertheless, these cases were rare and did not affect the overall outcome of the survey significantly.

5.3 RESULTS

5.3.1 Survey Response

The response rate for the questionnaires was good, possibly because the questionnaires were individually conducted on field trips. Response rates of the survey are summarized in Table 5-1.

Table 5-1 Questionnaire response rates for the island survey

Island Names	Survey Type			
	Questionnaires			Focus Group Discussions
	Targeted	*Achieved*	*Response Percentage*	*Conducted*
Haa Dhaalu (HDh) Kulhudhuffushi	30	28	93	1
Shaviyani (Sh) Funadhoo	30	29	97	1
Kaafu (K) Thulusdhoo	30	28	93	1
Dhaalu (Dh) Kudahuvadhoo	30	30	100	1
Thaa (Th) Vilufushi	30	29	97	1
Laamu (L) Gamu	30	28	93	1
Gaafu Alifu (Ga) Villingili	30	28	93	1
Gaafu Dhaalu (GDh) Thinadhoo	30	29	97	1
Seenu (S) Feydhoo	30	29	97	1
Seenu (S) Hithadhoo	30	28	93	1

Expected gender disparities were seen in participant pools, as most local councils were male dominated and would tend to refer males as more knowledgeable or more aware, especially about an issue that would traditionally be seen as a male-dominated industry. Participants were generally young or middle aged, with only 6% being above 55 years, and educated. A summary of demographic characteristics of survey conducted is presented in Table 5-2.

Table 5-2 Summary of demographic characteristics of respondents of the survey

Demographic characteristic		**Frequency**	**%**
Gender	*Male*	204	71
	Female	84	29
Living Situation	*Family with children*	212	74
	Family – No children	69	24
	Alone	3	1
	With non-family	3	1
Age range	*18 to 35*	176	61
	36 to 55	96	33
	Above 55	16	6
Status of employment	*Employed full-time*	191	66
	Employed part-time	10	3
	Self employed	54	19
	Unemployed	33	11
Level of Education	*No school qualifications*	31	11
	Secondary school	192	66
	Certificate/Diploma	52	18
	Undergraduate degree	14	5

5.3.2 Understanding of and Interaction with local coastlines and coastal protection methods

To appreciate the awareness of residents about their coastlines and coastal protection measures, it is important to first establish the relationship the residents have, to the islands. As there would seem to be no reason for a person to have this knowledge unless he has a vested interest in the island and a period of residence there. This relationship was established by determining residency status and duration, property ownership, family connections and employment opportunities. As shown in Table 5-2, almost all respondents were part of families either with or without children, and 88 percent employed full-time, part-time or self-employed.

The residency duration, and the residency and property ownership status of the respondents are shown in Figures 5-2a and 5-2b respectively. Almost 90 percent of the respondents have resided in the survey islands for more than 10 years and additional 4 percent more than 5 years. Others who lived in the islands for less than 10 years were mostly migrants from various islands, either for educational, social or environmental reasons including eleven who were migrants under population consolidation program after the tsunami 2004.

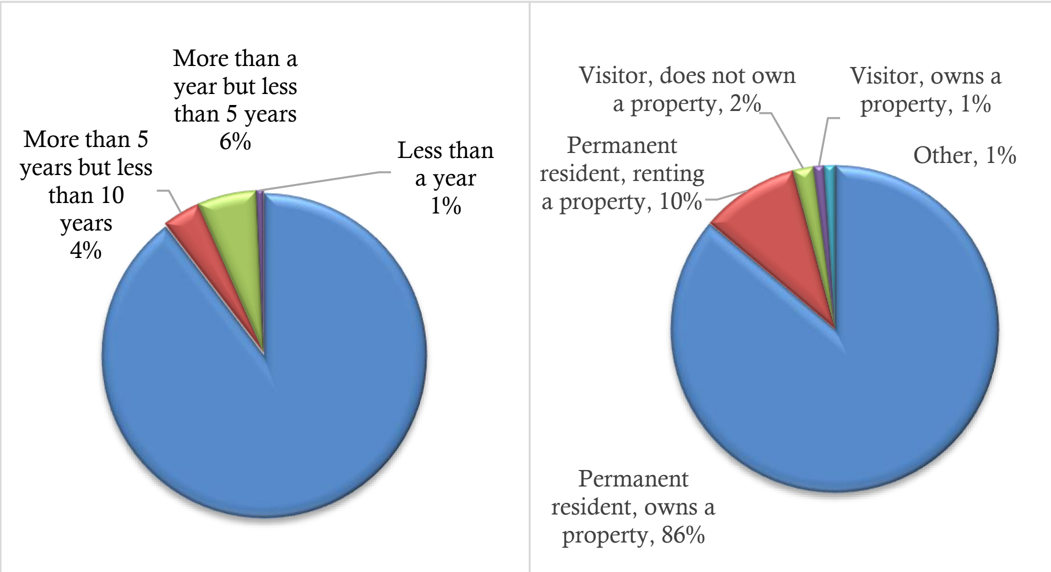


Figure 5-2 a) Residency and b) property ownership status of respondents

Approximately 86 percent of the respondents were permanent residents who own property in their respective islands. Ten percent of the respondents claim they are permanent residents renting in their own islands. Three percent of the respondents considered themselves visitors with a third of them owning a property on the island. However, discussions with the local councils reveal that the data may not represent a completely accurate figure for property ownership in some cases. One of the reasons highlighted was that some respondents considered where they live as their 'own properties' even though they are not entitled to property ownership. On the other hand, majority of the respondents from Thaa Vilufushi community answered, 'renting property' as their property ownership status, even though they pay no rent, because they all live in properties built by the government after the tsunami 2004 and that were not registered in their names. Nonetheless, since these cases were limited in occurrence in the former case, or possibly increased the figures for property ownership in the latter case, these misrepresentations seem to be trivial and do not detract from the proposition that the overwhelming majority of the respondents have a strong connection to the survey islands.

The frequency of visits to beach is one way to make sure the users are aware of the changes to their coasts. If they are frequent visitors there is high probability that they know what impacts their coasts both naturally and due to coastal modifications. Figure 5-3 shows the results when the respondents were asked how frequently they visit the beach in their respective islands in the past couple of years. Approximately 50% of the respondents claim they visit the beach on daily basis. While another 36% of the respondents visit once a week or more. Only 6% of the respondents have visited the beach once a month or less. These figures show that most participants interact regularly with their coasts.

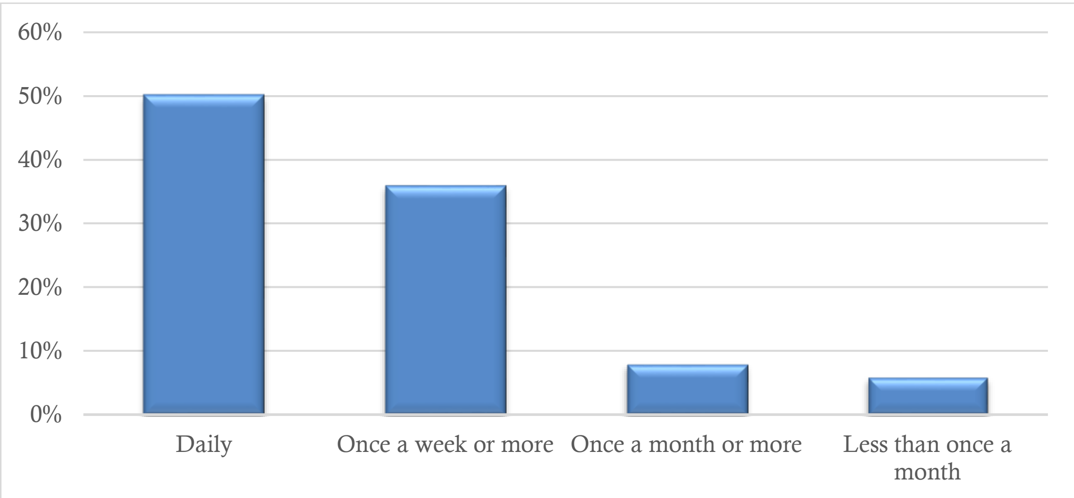


Figure 5-3 Proportion of respondents by frequency of visits to the coast in the previous year

Substantial research on stakeholders' visions for the future and local knowledge on different measures has been undertaken in some developing countries (Schmidt et al., 2013).

To ensure that stakeholder contribution in decision making processes were soundly based on a basic awareness and understanding of measures, the respondents were asked if they were familiar with the type(s) of coastal protection measures used in their respective islands. Just over half said they are familiar with the measures the rest are not familiar with the measures used. This was an interesting result, given that majority of respondents interacted frequently with their coasts. On closer investigation, it was found that while most residents visited the beach frequently, some did not necessarily visit the beach on the side of the island where coastal protection works would be done, or some only visited the beach to fulfil a personal or occupational need and thus may not spend the time, nor have the interest, to inspect the modification to their coasts. Moreover, the majority of those who visited the beach more than once a week were familiar with the measures. It was also learnt that while some residents did not have the inclination to keep up with the details of coastal modifications, in all the survey islands, there were a group of residents who took a keen interest and wanted to be involved in developments to their island such as coastal protection works.

In particular, when asked if respondents were familiar with specific coastline protection measures, a majority of the respondents showed an awareness of the more common types of measures implemented in RoM (Figure 5-4). For instance, more than 90 percent knew about reclamation and various types of breakwaters. Only a slightly lesser proportion knew about different types of sea walls and between 70 to 80 percent were familiar with revetment types and beach nourishment. Roughly half of the respondents were aware of groynes and gabions, a much less common measure in the RoM. On the other hand, only 21 percent and 9 percent of the participants had heard of managed realignment and beach ridge construction respectively. None of the participants acknowledged vegetation as a type of coastal protection measure. This may be because, compared to other types of hard and soft measures, vegetation is not predominantly promoted as a type of coastal protection measure. This demonstrates that most residents are familiar with the most common types of coastline protection measures used in the country and formed a fairly informed pool to draw stakeholders from, for consultations during decision making processes.

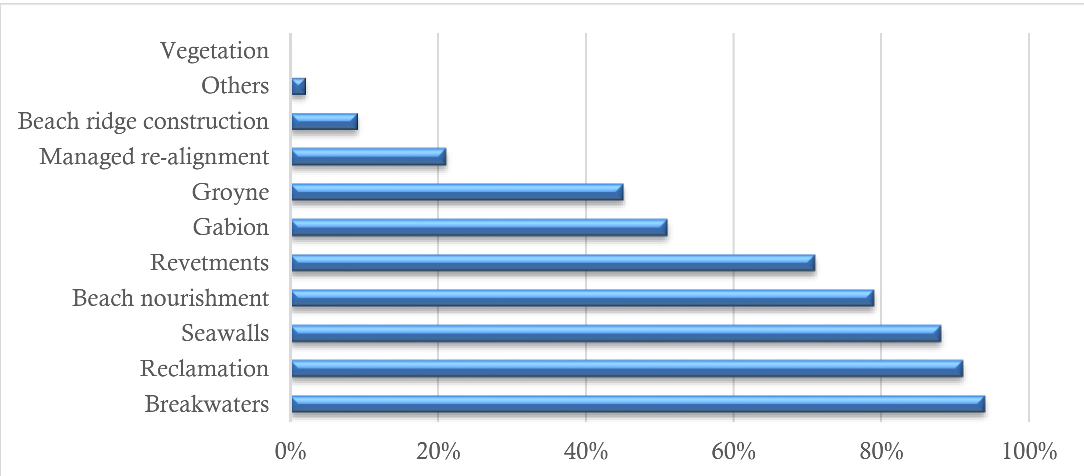


Figure 5-4 Proportion of respondents who were familiar with major types of coastal protection measures in the RoM

5.3.3 Contribution in Decision Making

Despite the residents being reasonably aware about coastal protection measures, the survey revealed that they were severely excluded from coastal protection decision making processes. Forty percent of the respondents declared that they were not even aware the current protection approach was being proposed. An additional quarter to a third of the respondents said that even though they were aware of the approach was being used, they were not involved in anyway. Of this latter group, only a handful of respondents admitted to being provided information in anyway, whether through public meetings, information brochures or surveys. In total, less than 30 percent either participated in focus group or interviews, attended any meetings, completed a survey or received information regarding a proposed coastal development and more than 10 percent of those who participated in this way were from Gaafu Dhaalu Thinadhoo alone. Figure 5-5 shows local stakeholder participation in various coastal protection decision making.

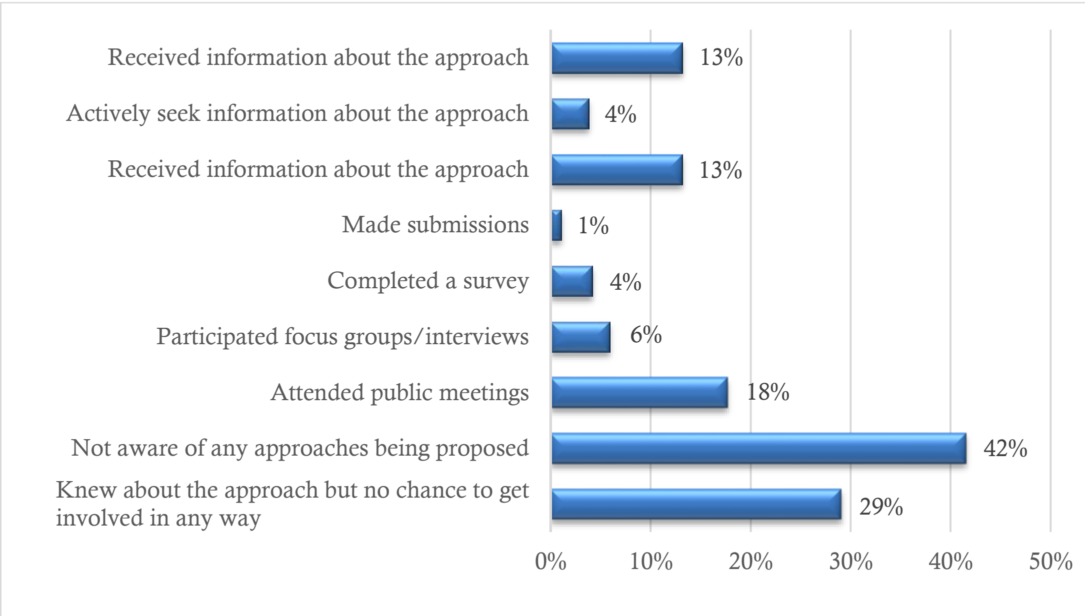


Figure 5-5 Proportion of respondents who contributed to decision making in various ways

Moreover, more than half of the respondents had different expectations of how the coastal protection measures would look in appearance, and on its impact on their use of the beach. Majority was not aware of the impacts of the measures and disagreed that they were adequately informed about the proposed measures. Most believed their involvement in the development process would have been positive. However, in terms of interest in the measures, while only about 40 percent said they were interested in it even before it was implemented; a third admitted they were not. This is plausible, given that they were not aware of the impact of the measure before implementation.

5.3.4 Public Opinions and Perceptions

5.3.4.1 Management of coasts

To gauge residents' perceptions and opinions on current coastal protection and management policy, respondents were asked regarding the current and expected roles of local and central government in managing the coasts and residents' satisfaction with the current policy and practices. Thirty five percent believe that their coasts are managed by the local authorities and less than 10 percent believe that that government does. A further tenth think it's managed jointly by local and central governments, residents and NGOs. It is apparent from this result that the specific roles of central and local governments in relation to coastal protection and management are not clear to the residents. Interestingly, a remarkable 44 percent of the respondents believe that no one manages their coasts. When the reasoning behind this response was further explored during focus group discussions, it appeared that while residents recognize that both central and local governments undertake coastal developmental initiatives, these initiatives are *ad hoc*, and thus, residents do not consider this to be management of their coasts. On the other hand, a comfortable majority of the respondents (63 percent) support the local authorities to be given this role rather than the central government. Only 16% of the respondents believe it should be jointly managed by central government and local councils. Moreover, more than 80 percent of the respondents expressed dissatisfaction with the way their coasts were being managed and protected. It is evident that decentralized decision making, or at least a change in the decision-making process is highly favoured by the residents when it comes to their coasts.

Due to the small size of the islands in the RoM, most of the buildings are close to the coast. A trend observed in all the islands is that island offices, and other older buildings and critical facilities such as power houses are located close to the coast. This may be because the settlements start from the most accessible areas to the island. Also, since the primary economic activities as well as the food source of the RoM historically was from fishing, it makes sense that people live close to the beach and as the population increased, they took more green area and spread inlands. Unlike other countries, coastal properties in the RoM were not considered high value properties until the year 2009, in which local tourism was introduced first time in the history (MEE, 2014). Rather, they are even believed high risk properties so people prefer to move inlands if the opportunity exists.

When the respondents were asked who should fund coastal protection measures when private properties are at risk, a third of the respondents thought that it should be solely funded by the central government and an almost equal proportion thought it should be solely funded by the local authorities (Figure 5-6). Only 16% of the respondents believe private owners whose properties are at risk should contribute in protecting the coasts. Most others thought it should be some combination of these three stakeholders. On the other hand, when public properties are at risk, 37 percent of the respondents believe central government should be solely responsible while a fifth thought local authority should be solely responsible. Another third deemed it to be the joint responsibility of central and local governments. When the respondents were asked who should fund protection measures when public properties when they are at risk and 58% of the respondents believe local governments should do it. Less than a tenth of the respondents believe private property owners living nearby should contribute since they are the people who are at risk of losing public properties such as road access. Some of the other reasons for the dependence on central government and local councils for coastline protection and management include: the cost of coastal protection would be unaffordable for private owners, relevant expertise may not be pursued, or appropriate solutions would not be implemented if private owners were given the responsibility.

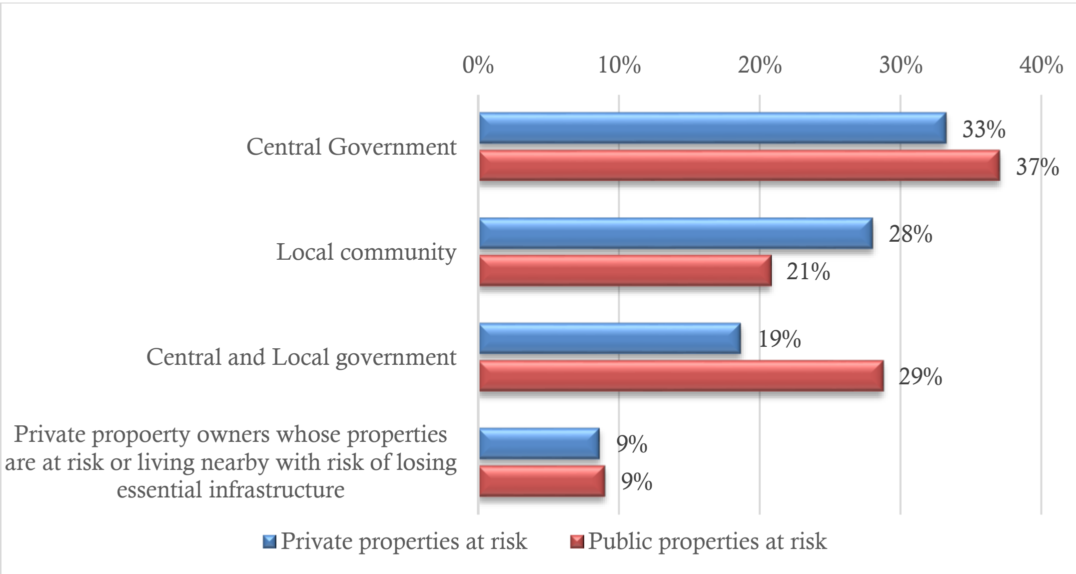


Figure 5-6 Individual respondents' views on which institutions (vertical axis) need to bear the financial burden of coastal protection when public and private properties are at risk. Horizontal axis shows the proportion of respondents who hold that view

5.3.4.2 Views on Coastal Protection Techniques

The respondents were asked to identify coastal protection measures that in their opinion would fit in seven different attributes used in the coastal protection decision making: aesthetics, defence, monitoring and maintenance, financial feasibility, durability, accessibility to vessels and environmental suitability. Rock armour breakwater was identified as the coastal protection measure that tops all the attributes except for accessibility to vessels, for which sea walls was the most favoured. Aesthetics and environmental suitability were the two attributes in which soft methods came up more favoured, but even in those attributes soft methods were less preferred to hard options (Figure 5-7). Given the severity and frequency of erosion that the islands are exposed to, and the difficulties in securing funding for coastal protection works, the communities have lower perception towards soft option and identified soft options unviable to combat coastal erosion. Even though soft options have worked in various other countries, participants of focus group discussions also expressed their concerns of the time and effort it takes to come up with a practical and successful coastal protection approach if soft methods were involved. Additionally, the protective properties of hard coastal protection measures over soft options (e.g. seawalls protecting the properties immediately behind them) and the opportunities hard measures would bring in such as easy access to islands, providing a safe haven for vessels, and loading and unloading goods and materials, are perceived benefits that would never be realised with soft-measures.

The coastal protection measures most appropriate to a specific island vary from island to island. Participants were asked which method of coastal protection they think is more appropriate for protecting their coasts. They were given ten different measures to choose from (Figure 5-8) and the most favoured protection measure was rock armour breakwaters (64%). In contrast, concrete breakwaters were favoured by only 2 percent. One of the reasons of rock armour over concrete breakwaters is that the damages to the material due to wave impact would be low in rock compared to concrete as rocks are natural. The second reason is because rock armours are easy to construct if the resources (material, machinery and manpower) were available. In the other hand, concrete breakwaters such as caissons and tetrapod are difficult to transport due to their shapes compared to rock armours. Issues such as requirement of larger yards/factory setups for prefabricating, and quality controlled manufacturing would be difficult. Concrete units also require higher levels of tolerances in the placement of units during breakwater construction.

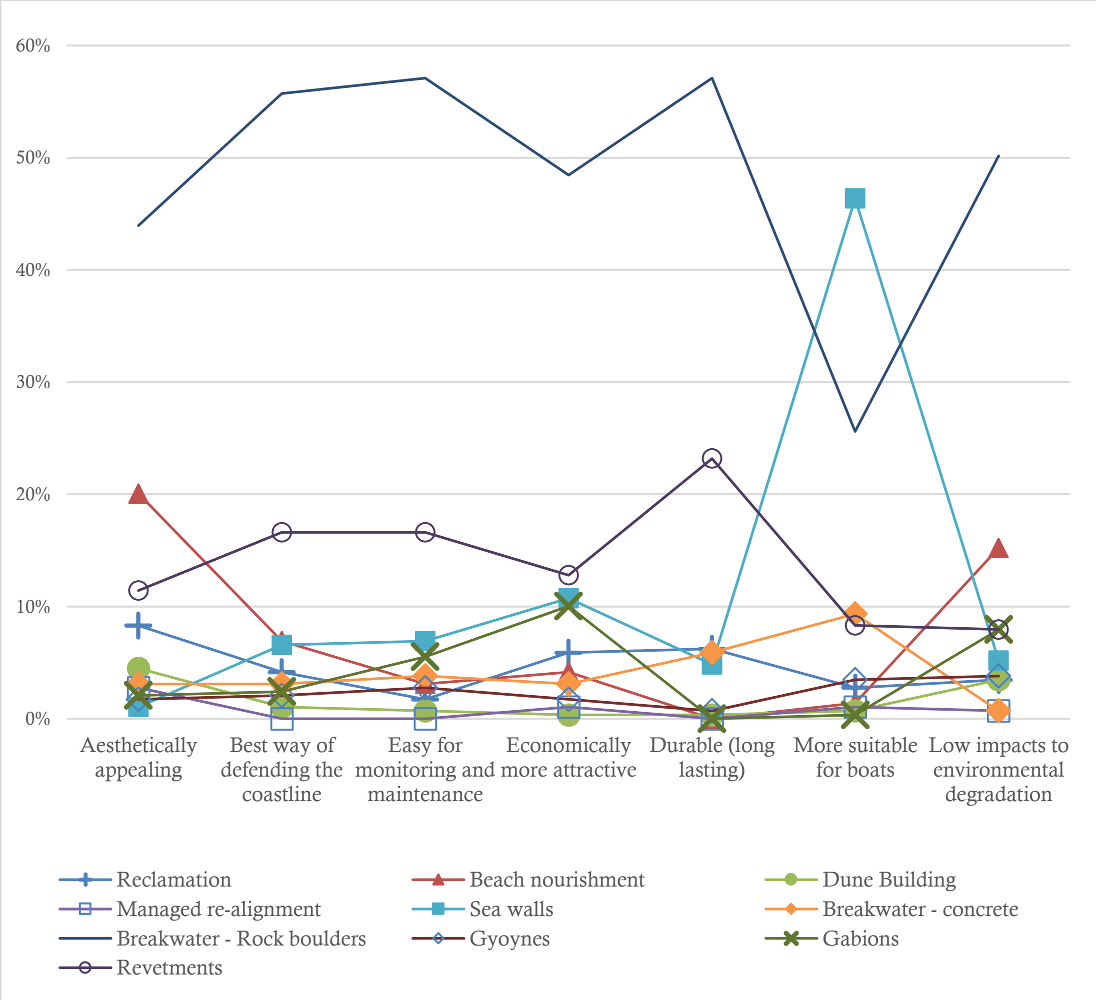


Figure 5-7 Proportion of respondents who viewed the suitability of different measures by their functional characteristics

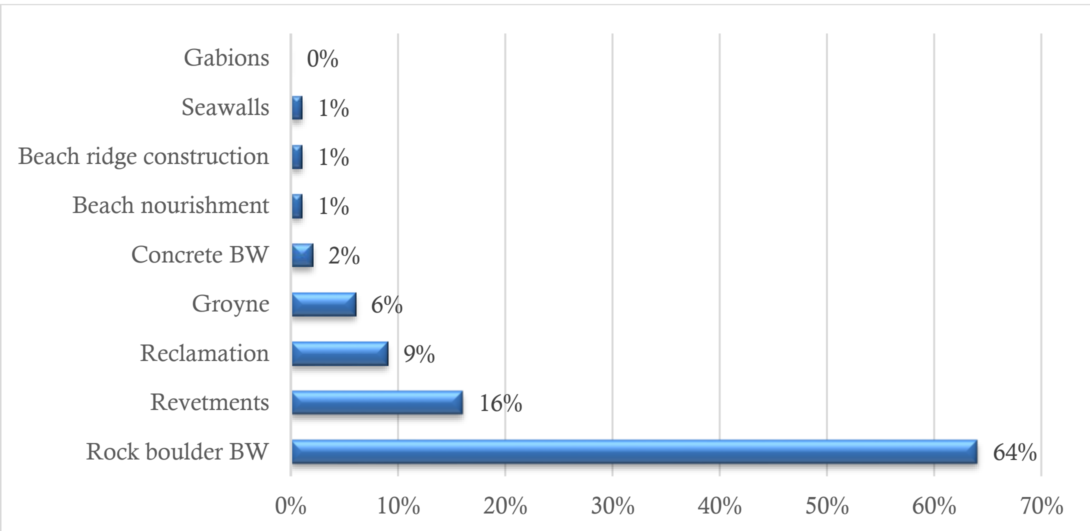


Figure 5-8 Protection measures that were viewed as most suitable for respondent's island

It was interesting to note that soft measures like reclamation and beach nourishment were favoured by only a tenth of the respondents, and reclamation accounted for almost all of those in favour. While the proportion of people who preferred hard structures such as rock armour breakwaters versus softer measures varied somewhat across the islands, the pattern remained the same (Figure 5-9). Some islands such as Kaafu Thulusdhoo and Gaafu Alifu Villingili this divergence was significant with all the respondents favouring hard options to soft, while additionally in Kaafu Thulusdhoo, more than 93 percent considered rock armour breakwaters to be the best for their island (Figure 5-10). Shaviyani Funadhoo, one of the most rural islands showed the highest preference for soft options with more than a fifth favouring reclamation. The possible reason is because the residents were promised an airport in the linked *Farukolhu* Island by the government and that would only materialise if a reclamation project is implemented. This preference is not because of the environmental acceptability qualities of the reclamation, but more a socio-political or practical concern. Some islands such as Seenu Hithadhoo showed more variability in their preference of the specific type of hard options, despite their overall inclination towards it, while others were less so. It is difficult to say that this preference is due to lack of awareness about soft measures, since, as identified earlier, well over three quarters of the respondents were aware of both reclamation and beach nourishment as protection measures. However, it is more likely that people do not view soft measures as permanent solutions to their coastal protection problems. This is even more likely since, of the soft measures people preferred, reclamation accounted for almost all the responses for soft measures and it is more likely that this preference is not due to an environmental concern, but rather a practical concern for land scarcity.

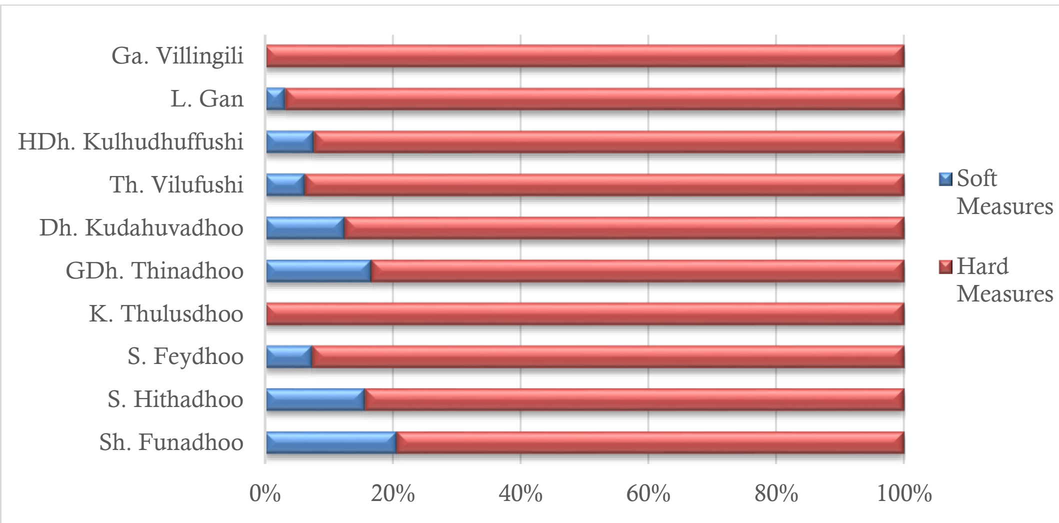


Figure 5-9 Respondents' presumption of suitability of soft versus hard options by island

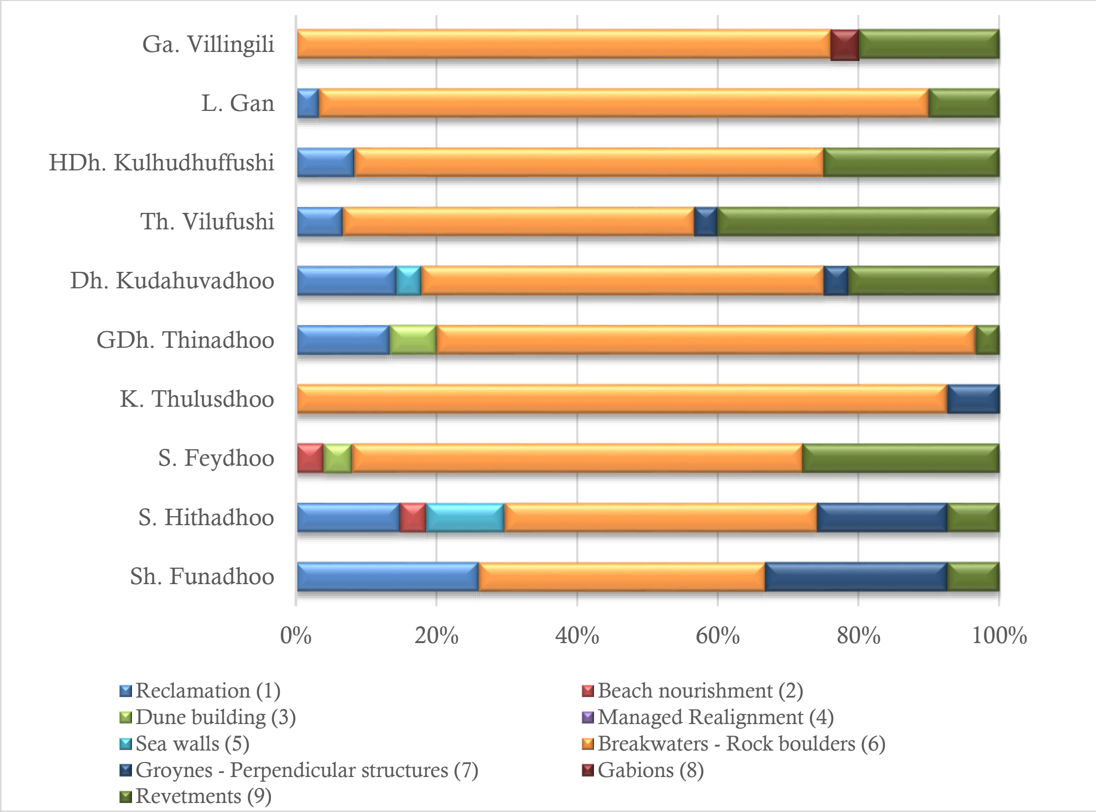


Figure 5-10 Perception of suitability of different measures by island

5.3.5 Valued attributes of coasts to public

Respondents were provided a list of valued attributes adapted from WRC (2011) that are relevant to RoM and they were asked to identify the importance of each attribute to them, using a scale of 'very important' (score of 4) to 'not at all important' (score of 0). The average ratings of the attributes are shown in Figure 5-11. The most valued attributes that ranked 'extremely important' were:

- Appearance of the beach (whether they are natural);
- Protection of scenic values when looking out over the beach and toward the sea;
- Retaining some undeveloped, natural beaches around the coast;
- Good recreational facilities in general (e.g. boat ramps, reserves, etc);
- Protection of scenic values when looking inland (e.g. towards houses or the surrounding landscape); and
- The involvement of local people in decision making about the coast;

Among the 14 attributes, the least highly-valued attributes are:

- The involvement of people who do not live locally in decision making about the coast; and
- Protecting beachfront property, even if it means losing the sandy beach.

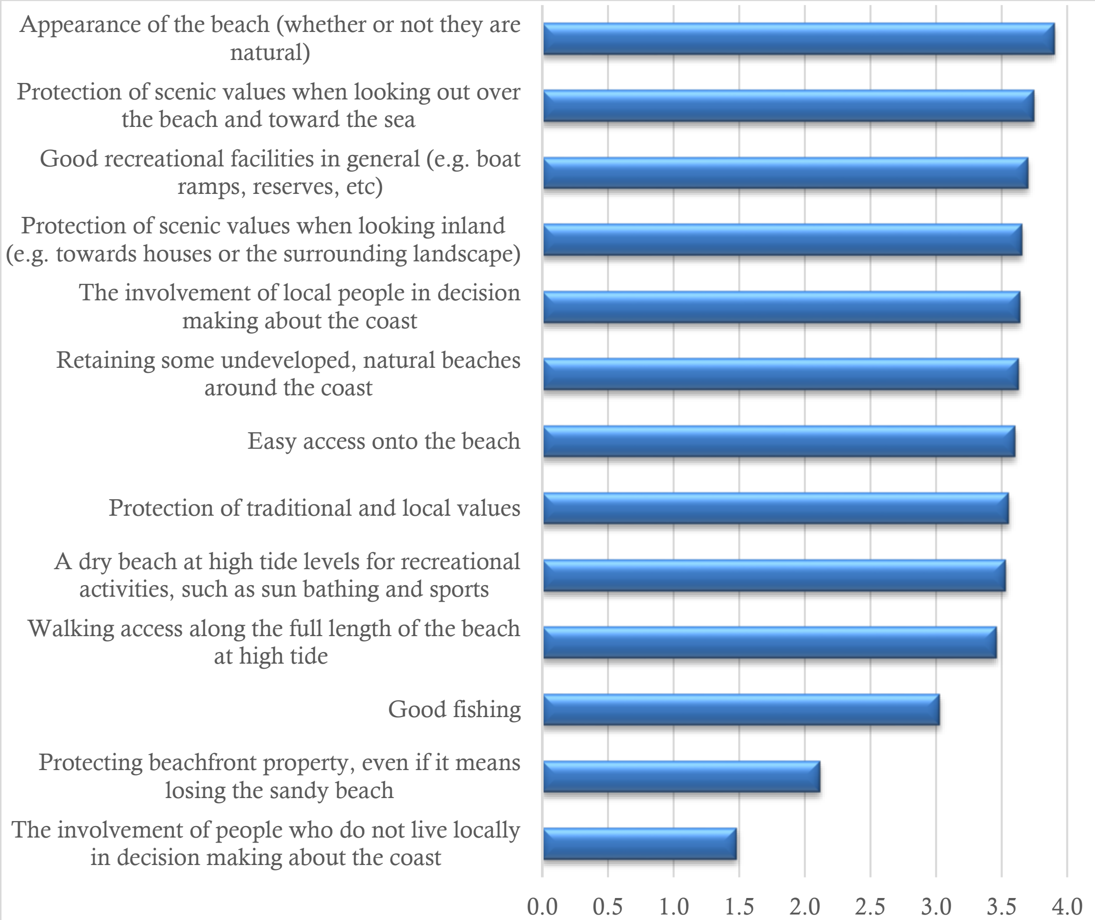


Figure 5-11 Attributes most valued by respondents about their coasts, by the average rating the attributes received

All the attributes apart from 'the involvement of people who do not live locally in decision making about the coast' have been considered 'extremely important' by most of the respondents. The results of the second least valued attribute 'protecting beachfront property, even if it means losing the sandy beach' shows that people have mixed views about the attribute. Beach front properties are not very common in the islands surveyed. However, due to the size and form of the islands, all properties are considered close to coasts. Therefore, a possible explanation of the scattered results might be that the people value the protection of beach front properties almost as much as they value the beach, and are unwilling to sacrifice one for the other. As expected, involvement of local residents in decision making was rated high while involvement of outsiders in decision making was rated low.

Analysis on the influence of demographic factors on respondents' value reveals no notable differences in any of the attributes. This was an unexpected result, since theoretically, fishermen or islands with a dominant fishing industry would value good fishing (and thus easier access and harbour facilities) over the appearance of beach, while those working in the tourism sector would opposite value preferences.

5.3.6 Risks and Hazards

Although, coastal engineers work hard to bring sound engineering plans to work with, their knowledge of island specific natural hazards in the RoM is mostly based on assumptions due to the lack of monitoring and data. It is believed that the residents who live in the islands for a very long time know what risks are most likely and what hazards they have faced, giving engineers more accurate data to tackle coastal protection issues. Respondents were given five different options to choose from the main natural hazards that they consider most likely to affect their islands (Figure 5-12). Majority of the respondents find flooding is the key natural hazard to their islands. The second most likely hazard was sea level rise followed by storm or cyclones with high winds and tsunamis. No respondents believe earthquakes are a likely occurrence to their islands. The perceived risk of inundation by flooding or sea level rise is backed up by data that shows, in 2004, over 97% of inhabited islands experienced beach erosion, of which 64% of the cases were reported as severe beach erosion (UNDP, 2013). The second national communication of Maldives to UNFCCC highlighted the rate of SLR in Male' and S. Gan as 3.75mm and 2.93mm respectively (MEE, 2016).

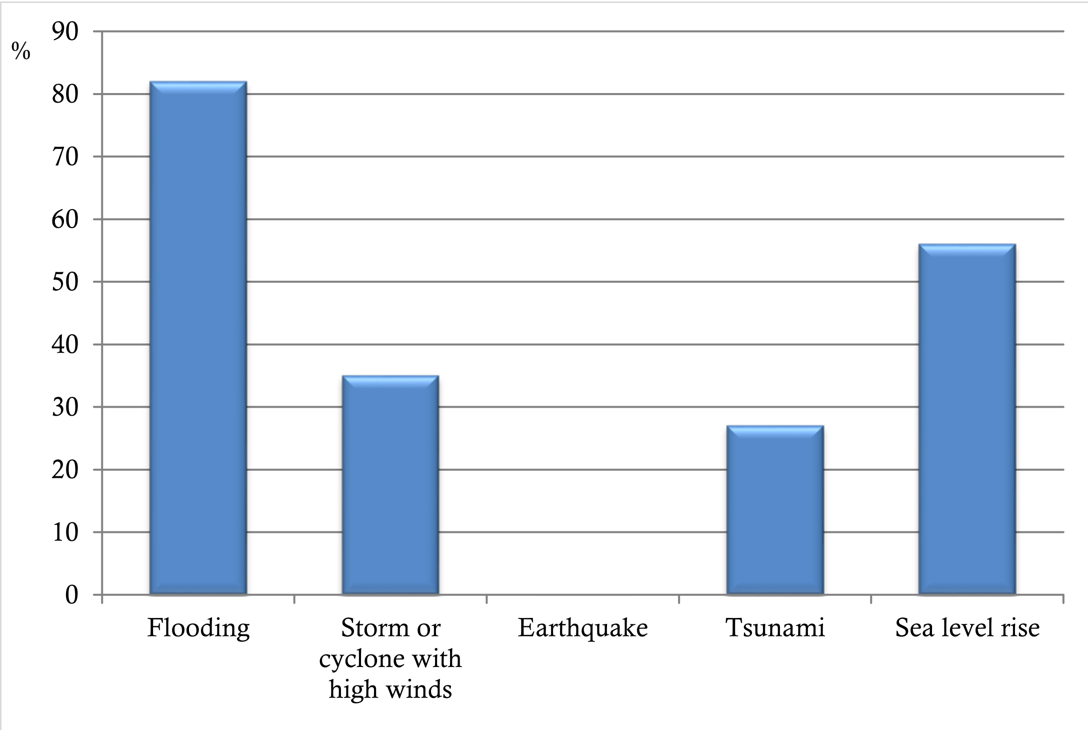


Figure 5-12 Distribution of respondents by perception of most likely hazard to their island

With the same set of natural hazards, respondents were then asked if they have personally experienced or suffered loss or damages due to any of the natural hazards. Approximately 76% have personally experienced tsunami 2004, of which half have also experienced losses and damages due to the tsunami 2004. A quarter of respondents have experienced storms or cyclone with high winds, of which 10% experienced losses and damages. Only 1% of the respondents have experienced earthquakes while there were no personal experiences of or losses from sea level rise.

It is interesting to note that even though 56% of the respondents (Figure 5-13) believe sea level rise is one of the two most likely natural hazards to their islands, no one has personally experienced it. It is likely that due to the subtle nature of SLR, it may be imperceptible to residents and the consequential effects of SLR on other hazards may be unnoticeable to common people.

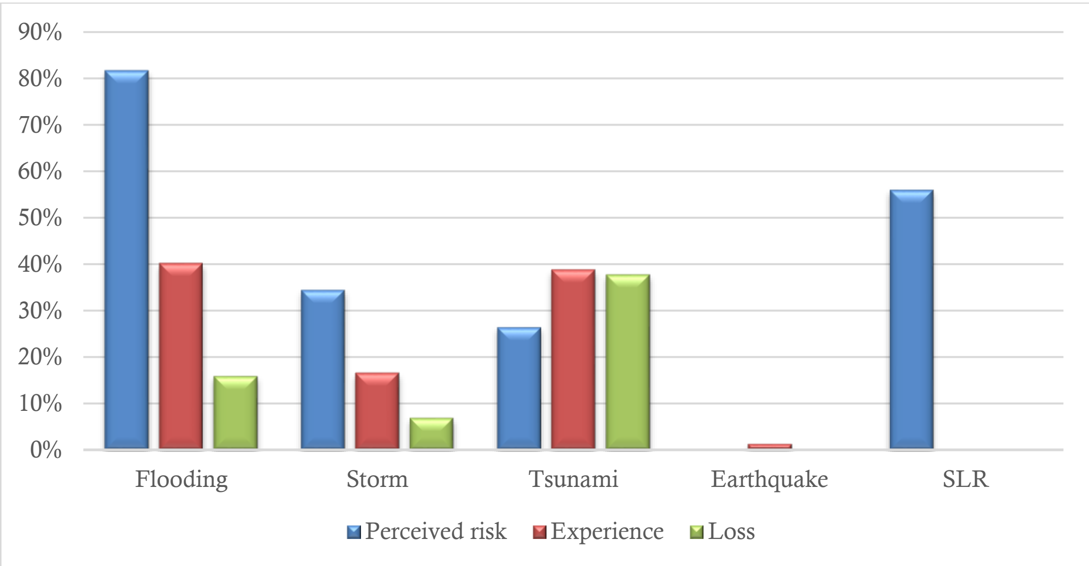


Figure 5-13 Distribution of respondents by personal experience of and losses from different natural hazards compared to the perceived risk of those hazards

Nearly seventy percent of the inhabited islands reported beach erosion in 2013 at different scales and of different severity (MEE, 2015). Respondents almost unanimously agreed that coastal erosion is happening and it must be controlled. More than half of the respondents believe erosion occurs due to sand mining. As construction materials are expensive some islanders mine sand from coasts and lagoons to acquire fine sand as a substitute for fine aggregate for concrete and plastering (MTCC, 2014). Changes in the sand supply to the beach by natural means and structural changes to coasts came in second and third as the main cause of coastal protection. Respondents believe sea level rise, coral mining and storms have the least impact on coastal erosion (Figure 5-14).

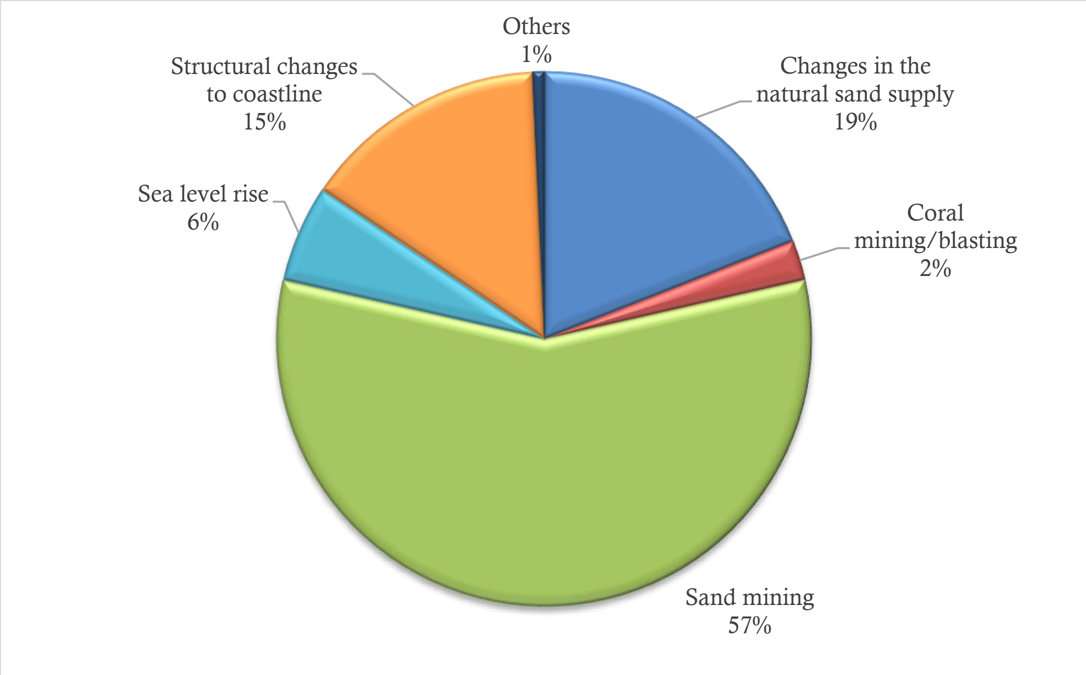


Figure 5-14 Distribution of respondents by perception of main cause of coastal erosion in islands

Majority of the respondents were worried that coastal erosion may result in a loss of natural environment (Figure 5-15), while there was small proportion who were concerned about depletion of sand. The least concern for the respondents is loss of benefits for local community (4%). Loss of enjoyment for the visitors (8%) was not a big concern, since none of the islands surveyed were resorts or tourist destinations.

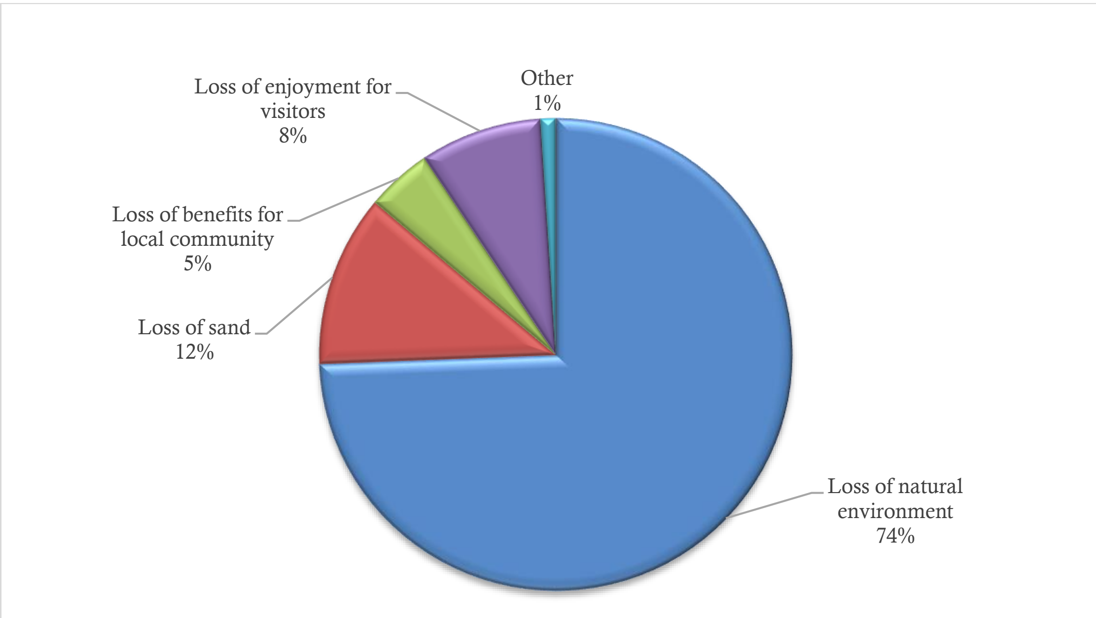


Figure 5-15 Respondents' main concerns about the effects of coastal erosion in island

5.3.7 Secondary observations

Types of Coastal protection methods implemented in survey islands

All the islands surveyed had more than one coastal protection measure installed, which is typical for most islands in the RoM. They ranged from four measures up to seven in Seenu Hithadhoo (Table 5-3). All islands except Kaafu Thulusdhoo had a seawall while Thulusdhoo had a jetty. Jetties are becoming very uncommon in the RoM as they are being replaced with seawalls or quay walls for access. Most islands also had offshore and/or nearshore breakwaters and had some amount of reclaimed land. All islands except Thaa Vilufushi had coastal vegetation to combat erosion while only Kaafu Thulusdhoo and Seenu Hithadhoo had groynes.

Although coastal erosion was only identified as a severe problem in Seenu Hithadhoo relatively recently according to MHE (2011b), the island has most number of coastal protection measures implemented. This may be because the island is one of the largest in the RoM and the most populous islands among the group of islands surveyed, the probability of the lives and livelihoods that would be impacted from a coastal protection related hazard incident is high for Seenu Hithadhoo.

Some of the breakwater types (tetrapods, jumbo bags, caissons, steel sheet piles) and groynes are uncommon in the surveyed islands. This may be because the construction methods are difficult, the measures are costly, the material are not readily available or the people are reluctant to use new options on their coasts even though they are tested and worked in other countries. Coral mound became obsolete in the RoM as they are identified as environmentally unacceptable for coral islands (MHI, 2014). Although sand-cement bags are easy to construct, they are becoming an unpopular practice because of their low resiliency and stability under severe wave conditions.

Table 5-3 Summary of different coastal protection measures in survey islands (Checked boxes indicate the availability of technical category or measures in the island)

Technical Category & measure names	Survey Islands									
	Kulhudhuffushi	Funadhoo	Thulusdhoo	Kudahuvadhoo	Vilufushi	Gamu	Villingili	Thinadhoo	Feydhoo	Hithadhoo
Break Water	✓	✓	✓	✓	✓	✓	✓		✓	✓
Rock armour	✓	✓		✓	✓					
Tetrapods/Caisson/ Geo bags/ Steel sheet										
Sand Cement Bags							✓		✓	✓
Revetments	✓	✓		✓	✓	✓	✓		✓	✓
Sand Cement Bags		✓								
Precast Concrete		✓								✓
Rock armours	✓			✓	✓	✓	✓		✓	✓
Reclamation	✓		✓	✓	✓		✓	✓	✓	✓
Seawalls	✓	✓		✓	✓	✓	✓	✓	✓	✓
Concrete	✓	✓		✓	✓	✓	✓	✓	✓	✓
Steel Sheets	✓							✓		✓
Sand Cement bags							✓	✓		
Groynes			✓							
Vegetation	✓	✓	✓	✓		✓	✓	✓	✓	✓
Beach nourishment	✓				✓	✓		✓		✓

Implicit knowledge of stakeholders

The focus group discussion held in each survey island, with key stakeholders revealed that every island had a pool of residents who had detailed implicit knowledge of the island. This ranged from local weather patterns, erosion/accretion patterns and locations, to history of coastal modifications in the island and the aftermath and outcomes from installation projects. Sometimes some of this information is collected during pre-project stakeholder consultations but it is usually only used for that specific project since there is no mechanism to record or share such information across projects and especially across project teams and between companies. However, once a project is completed, the aftermath, outcomes, success or failure is only ever, if at all, a matter of concern if the system is being modified or replaced.

Local key stakeholders also possess vital information about peculiar weather patterns that affect those islands and which can significantly affect the successful installation of a system. For instance, in the island of *Gnaviyani Fuahmulah* (not included in the survey), the key stakeholders are aware that any coastal protection works on the eastern side can only be carried out during a particular period of 36 days that correspond to three *Nakaiy*-monsoons (*Assidha* - April 8th to April 21st, *Atha* - September 21st to October 3rd, and *Hitha* - October 4th to October 17th). Outside of this small window, the island experiences severe wave action all year round which makes any offshore work impossible. Thus, during the last project implemented by MTCC to install a breakwater round-head the workers stood by until the window approached in *Atha* and worked round the clock to finish the work within the small time-frame. That critical piece of information led to the successful completion of that project. Similarly, local residents are aware that in Dhaalu Kudahuvadhoo, that within a timeframe of 30 years, the erosion and accretion in the island balances out.

These types of information are not recorded or stored even in the island offices, and consequently means that these pools of key stakeholders are the only source of this significant information. Accordingly, it seems vital that in order to make effective decisions regarding local coasts, they form part of the decision-making process.

5.4 DISCUSSION AND CONCLUSIONS

Having conducted a survey and a set of focus group discussions in ten populous islands in the RoM, this research assessed stakeholders' perception on coastal protection works and the communities' role in coastal protection decision making. It also identified communities' views on the factors that contribute to coastal degradation, measures they desire would bring positive changes to their coasts, and the impacts to current mechanism if the level of stakeholder contribution is increased.

The research suggests that local communities not only understand and are concerned about the changes that are taking place in their local coastlines, but also know about what has been done to address the problem and are able to evaluate the value of these interventions. It was observed that knowledge and awareness of coastal protection measures and perceptions of successful systems was somewhat determined by the types of measures residents were exposed to, and less common measures did not fare well in their judgment of effective measures.

Stakeholders believe their involvement in the decision making would help decision makers to select appropriate measures thus reduce the environmental impact on the coasts. However, the research identified that a relatively low percentage of the local stakeholders get the opportunity to contribute in the coastal protection decision making. Additionally, an inadequate amount of information is disseminated about the measures even though people wish to be actively involved in the decision making. The laws and regulations related to coastal protection works in the RoM such as Environmental Protection and Preservation Act (EPPA) of the Maldives (Law 4/93), and Regulation on Reclamation and Dredging of Islands and Lagoons Areas in the Maldives 2013, do not make stakeholder engagement compulsory. However, with the amendment of Environment Impact regulations in 2007, a certain degree of stakeholder involvement is required to be included in the Environmental Impact Assessment (EIA) reports. The findings of the research suggest that while stakeholder consultations may not benefit all stages of decision making, in the initial stages such as problem identification, including residents' knowledge can improve decision making significantly.

With regards to coastal protection policy, stakeholders do not view that Do nothing is an acceptable policy for RoM, and while they are slightly less reserved about Managed realignment, even this is not seen as a permanent solution to the coastal protection problems in RoM.

Coastal flooding and inundation linked to SLR were identified as the most likely hazards even though people who have practically experienced the hazards are less. Considerably less number of people have first-hand experience of storm and cyclones and the hazards are considered less likely. Moreover, tsunamis were seen to be less likely to occur, even though a significantly large number of respondents were affected by the tsunami 2004. Estimated tangible losses from natural hazards and catastrophes are significantly high to islands. DIRAM's estimate of MVR 668'115'832.5 tangible losses from tsunami, swell waves or storm and rainfall flooding to the ten islands suggest protection of the islands from such hazards must be a priority.

The results suggest that human intervention such as sand mining and, to a lesser extent, coastal modifications play a role in coastal erosion in the islands. Although sand mining from islands has been banned since March 2000, it is still practiced in some islands. The reason behind sand mining could likely be the high cost of imported fine sands/aggregates in the Maldivian market. Another reason of coastal erosion was perceived to be the decline in natural sand supply to the beach. There are evidences that coral growth in the Maldivian reefs have been adversely affected after 97 and 98 El Niño, and this could affect the sand supply to the beaches in the future. With the enforcement of EIA regulations, it is believed that proper studies will be conducted before coastal modifications are decided to minimize impact on erosion.

5.5 CHAPTER SUMMARY

This chapter presented the results of a public opinion survey conducted in ten inhabited islands in the RoM. The survey aimed to understand local stakeholder's contribution to and awareness of coastal protection works in the islands. The results reveal that most local stakeholders have an adequate understanding and awareness of both their coastlines and protection measures. However, a relatively small proportion of them get the opportunity to contribute in any form in the coastal protection decision making process. The survey also revealed that current mechanisms for coastline management are less than satisfactory. Local stakeholders show a significant preference towards hard techniques and perceive that exclusive use of soft options are not adequate for protecting their coastlines. In the next chapter, professionals' perception of coastal protection works in the RoM, some of these views are further validated.

6 PROFESSIONALS' PERCEPTION OF COASTAL PROTECTION WORKS IN THE REPUBLIC OF MALDIVES

6.1 INTRODUCTION

This chapter presents the results of a perception survey conducted in the RoM to recognize the views of relevant professionals on coastal protection works in the RoM. It identifies the current state of coastal protection decision making, planning and management approaches, and common coastal protection measures in the RoM. In addition, this chapter validates the key parameters and factors identified through the literature review to confirm their applicability to a coastal protection DSF for the RoM.

6.2 SURVEY METHODOLOGY

The general aim of this chapter is to identify professionals' perception on areas important in the formulation of a coastal protection DSF for the RoM. The objectives are:

(1) to understand professionals' attitude towards the common coastal protection measures used in the RoM, and

(2) to validate different parameters and factors for coastal protection decision making obtained through literature review.

Areas covered in the survey include the use and application of DSF, planning and management approaches, common coastal protection measures in the RoM, and technical viability, multi-hazard resiliency, and socio-aesthetic and environmental acceptability features of different coastal protection measures.

To better understand professionals' perception, and to probe through some of the specific areas of coastal protection in the RoM, this research relied on face-to-face semi-structured interviewing. Although, a questionnaire was initially designed using Qualtrics™ software for professionals' perception survey, initial focus group discussions to validate the questionnaire with the experts in RoM identified that semi-structured interviewing would be more useful over a survey questionnaire. One of the main advantages of using semi-structured interviewing was the opportunity it provided to actively engage with participants to identify their real life experiences and knowledge that would not be realized through a survey questionnaire (Babbie, 2004).

Potential participants for the survey have been identified by approaching major coastal protection contractors, consultancy firms, relevant government institutions, and free-lance consultants actively involved in coastal protection projects at the time of the survey. The selection of participants from contractors and consultants were based on their relevant experience and educational background in the coastal protection sector. To identify prospective participants from relevant government institutions, requests were made to identify policy level officers who are willing to take part in the study. Separate letters of invitations were sent to the participants once they were identified by their respective agencies or firms. Participants from local islands were identified, contacted and interview arrangements made through their respective island councils. Invitation letters to the participants included a brief outline of the research, aims and objectives, and an abstract of the study. Interviews were conducted either in a place preferred by the participant or a neutral place to both researcher and participant.

A total of fifty-two semi-structured interviews from 45 to 60 minutes were conducted at different locations by the researcher. Table 6-1 summarises the stakeholder groups and the number of interviews requested and completed. Confidentiality and anonymity was assured to all participants. Participants were not directed or forced to answer in a specific way and their answers were taken at face value. Interviews were audio-recorded and later transcribed for analysis. This was supplemented with additional physical notes by the author.

Table 6-1 Target groups and stakeholders for the professionals' survey and the types of information collected from the groups

Target groups	Information collected	Stakeholders	Number of interviews
Coastal Contractors/ Consultants	• Coastal protection in the RoM	• Civil Engineers • Coastal Engineers/Managers • Consultants	8 8 4
Policy Makers	• Coastal protection in the RoM • Policy information, • Roles and responsibilities of Government Ministries	• Ministry of Housing and Infrastructure (MHI) • Ministry of Environment and Energy (MEE) • Environmental Protection Agency (EPA)	8 5 3
Key professionals from local islands	• Coastal protection in the RoM	• Island development committee members	16

6.3 RESULTS

6.3.1 Coastal Protection Decision Making in the Republic of the Maldives

A literature review conducted recognized that no DSFs have been used in the RoM for coastal protection decision making. This finding was backed up by the professionals interviewed. Most participants are not familiar with any DSFs or coastal protection decision making tool or framework and over a third of participants confirmed that no DSFs have been used in decision making. Over 60% of the participants have indicated that United States Army Corps of Engineers (USACE) Coastal Engineering Manual and The Guide to Coastal Erosion Management Practices in Europe (Eurosion guide) are sometimes used as guiding principles. A few of participants indicated 'international best practices' are being followed in the coastal protection related decision making. Most participants following international standards and guidelines show they have the need and desire to use systematic evaluation tools and frameworks. Indeed, almost all the participants confirmed that a coastal protection DSF is a vital instrument for the RoM to select appropriate coastal protection measures, and commented on the positive outcomes that it would bring to the country let alone the construction industry.

Figure 6-1 shows their preference of evaluation parameters for building a DSF for the RoM. All the participants were in favour of 'construction', 'cost' and 'durability'. A vast majority also believed 'design reliability', and 'hazard and vulnerability' are crucial factors for the DSF. Almost two thirds of the participants considered the factors 'environmental sustainability' and 'socio-aesthetics' to be important to be addressed in the DSF as well.

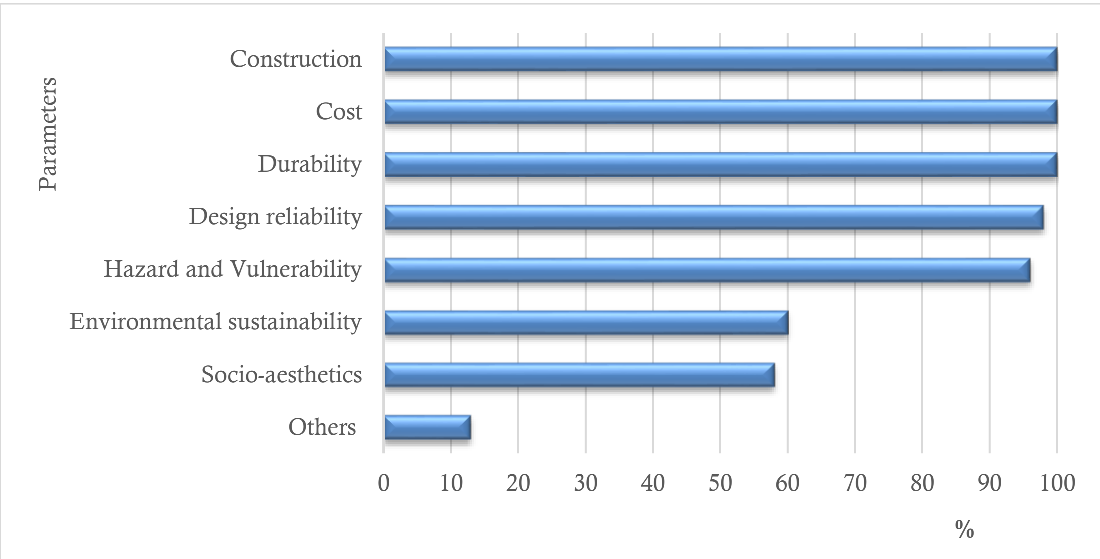


Figure 6-1 Distribution of professionals by key evaluation parameters suggested for use in a coastal protection DSF for the RoM

Other parameters suggested were ‘strategic importance’, ‘social acceptability’, and ‘applicability to the specific local islands which they are being applied to’. The results indicate that the professionals believe there is a strong need towards making the structures more resilient, reliable and cost-effective rather than aesthetically appealing.

With regard to benchmark frameworks, seventy percent of the participants preferred DSFs from both developed countries and island nations for a better result. Twenty nine percent suggested that frameworks designed especially for island nations would be better due to similar physical characteristics and experience dealing with similar issues. The rest of the participants felt there was no need to benchmark because the nature of the problems to each country would be unique and different.

In terms of using cost-benefit analysis (CBA) or financial feasibility studies for finalizing coastal protection projects in the RoM, 22% of the participants, mostly policy makers, acknowledge that some form of financial feasibility are done, and are considered an important part of the current decision-making process. On the other hand, most of the participants, who do not take part in the final decision making, identified they are not aware of the CBAs or feasibility studies. One of the participants argued that current decision-making protocol does not include CBAs and hence disregard qualities of the final product. Moreover, only 13 per cent of the participants believed that delivery of projects is improved through lessons learnt from past projects including installation of incompatible measures. The vast majority of professionals were not aware of this practice due to lack of procedures established for such knowledge transfer, and the participants being contractors who focus on delivering a task rather than bringing improvements.

In the RoM, the mandate of coastal protection and infrastructure development projects are planned and executed under two different ministries. The majority of the participants believed that cost cut down from coastal protection projects would be realized and resource duplication would be minimized if the mandate was assigned to a single ministry. An opposing view was the mandate is too big for a single ministry due to the geographic dispersion of the islands that allocating all the work to a single ministry would slow down the process and increase the cost and time incurred.

With an increase in the international funding for coastal protection and other mitigation works, the pressure for project transparency and accountability is increasing. One way of improving transparency and accountability is to involve stakeholders in the planning, implementation, monitoring and evaluation of projects (Dinshaw et al., 2014a). Although coastal protection projects are mostly carried out in the islands the preconstruction work, including design finalization, feasibility, and decisions on type of measure are being made by a small group of decision makers in Malé (MEE, 2014). Over 90% of the professionals agreed the process would improve with increased local stakeholder contribution. The remaining participants who are mostly from government ministries disagree, and argue that active local stakeholder participation would bring in project delays and unwanted and unresolvable problems.

Transparency is even more pressing in a context such as RoM where coastal protection project selection is perceived to be politically biased (Figure 6-2). This was evidenced by the fact that functional coastal protection measures in some islands have been replaced with very similar measure with no obvious benefits, and repeated projects of similar nature have been implemented in a specific island consecutively, and minor coastal problems in specific islands have been attended to while some other nearby islands have experienced severe erosion for years. In addition, participants claim that in some instances the most suitable location for coastal protection measures identified through physical surveys and EIAs have been changed to sites favoured by leading political figures in the islands, regions or the government. It is interesting to note that the small group of participants who opposed the view of political biasedness in the coastal protection decision making are all policy makers from government institutions.

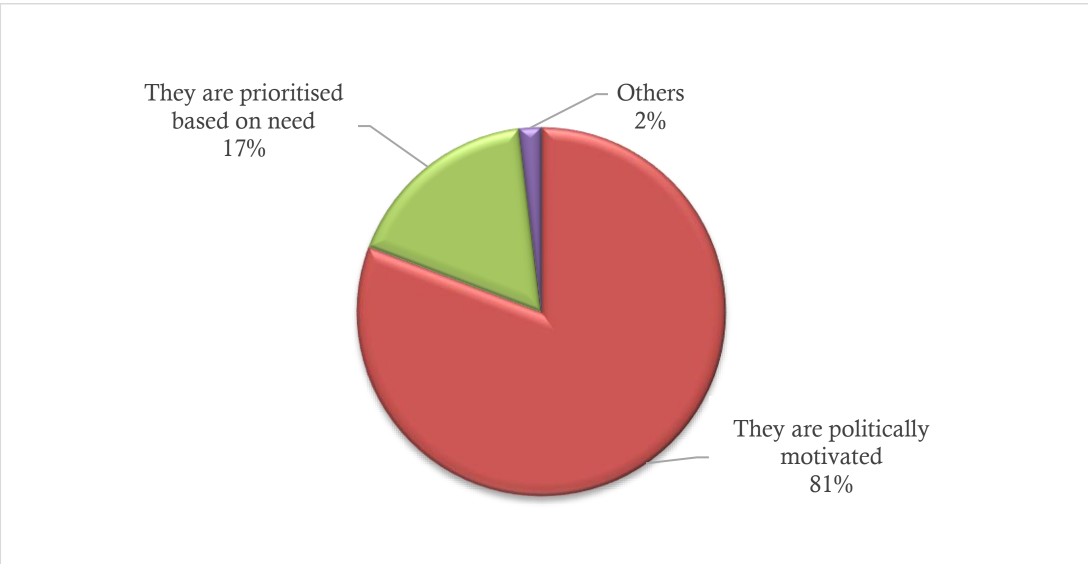


Figure 6-2 Professionals' perception of biases in coastal protection project selection and decision making in the RoM

6.3.2 Coastal Planning and management approaches

Given the seriousness of coastal erosion and coastal flooding in the RoM and IPCC's projections on local SLR, participants were asked which 'planning and management' policies would work best for the RoM, from five universally accepted policies. Figure 6-3 shows the workable planning and management policies the participants identified as best suited policies for the RoM

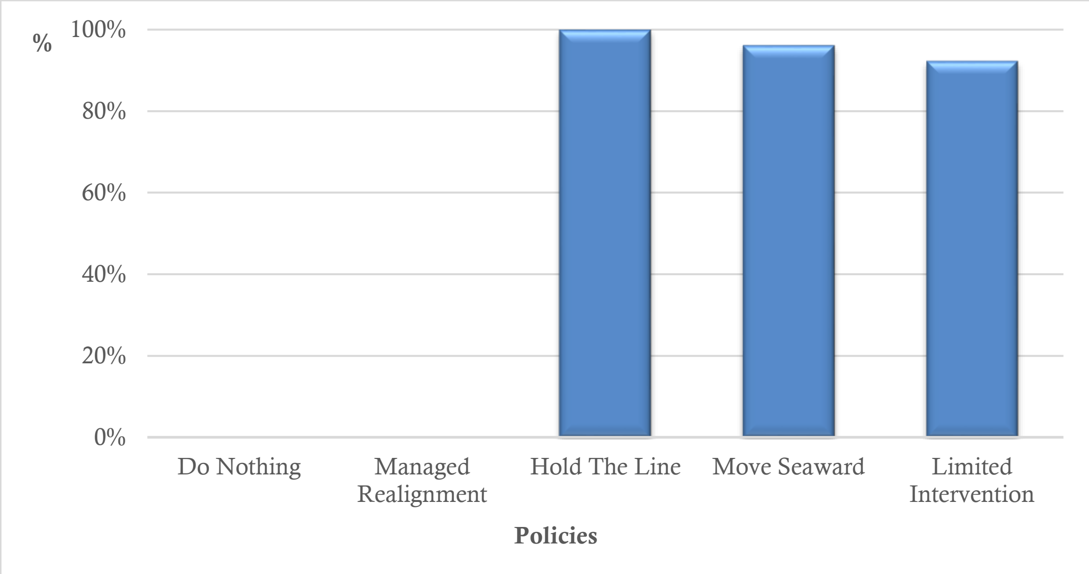


Figure 6-3 Professionals' views on workable coastal protection planning and management policies for the RoM

'Hold the line', 'move seaward', and 'limited intervention' are the policies identified with 100%, 96%, and 92% of the participants agreeing them as most suitable policies for the RoM respectively. Participants unanimously agreed that 'do nothing' and 'managed realignment' policies are impractical to the RoM due to the geophysical setting of the islands. They acknowledged the severity of coastal erosion problem across the country and believed 'do nothing' will likely inundate large parts of the islands while 'managed realignment' would not work for countries like the RoM because of the small land area and the absence of higher grounds in the islands.

Environmental vulnerability and fragility of the physical characteristics of the islands were further recalled by the tsunami 2004. The 'nation-wide disaster caused severe damage to the physical infrastructure of many islands across the country' (UNDP, 2013; WorldBank, 2005). Total damages of MVR7,447 million, which was 62% of GDP, was estimated that do not reflect the indirect cost of environmental damages including substantial 'coastal erosion on many affected islands' (UNDP, 2013; WorldBank, 2005). Despite this experience, majority of professionals interviewed were either unaware of any additional safety features incorporated into coastal protection works after the tsunami 2004 or are not in positions to understand the safety measures as policy and regulatory changes are not fully disclosed to the public. Forty percent of the participants identified that some safety features have been incorporated since the tsunami 2004, such as:

- improving structural resiliency of the measures against multi-hazards,
- increasing crest height of seawalls from 1.5 to 2 feet from land height,
- replacing some of the sand cement bag sea/quay walls with concrete panel walls,
- introducing a setback line for the first time,
- introducing provisions for drainage behind quay, and
- replacing sand cement bag breakwaters in many islands to rock armour/armour

Over 90% of the participants believed the country has no financial and technical capacity to deal with coastal erosion and coastal flooding in the 180 inhabited islands, and considered it would be uneconomical to tackle the problems in all the inhabited islands. They also support the population and development consolidation program initiated by the government of the RoM in the 1990s, which encourages relocating people from smaller islands that are highly vulnerable to multi-hazards onto larger islands that are identified as safer. However, they believed relocation must be voluntary and never be forced. In addition, they expressed concern over the rejection faced by some of the migrant communities and suggest that creating awareness within the existing community to accept the migrant community as part of their community is equally important. Interestingly, few of the participants believed the revenue generated from tourism alone would be sufficient to tackle coastal protection problems in all the islands, and believed there is no need of relocation if the islands were protected with effective coastal protection measures.

6.3.3 Coastal protection measures

There is a debate among coastal protection professionals on what coastal protection measures would work best for the RoM where over 80% of the islands are facing severe coastal erosion. Half of the participants believed hard engineering is the only way forward for the RoM given the severity of coastal erosion and coastal flooding problems and the fragile geophysical setting of the coastlines while the other half agreed that combined approaches of soft and hard protection options are more effective in the RoM case. The few participants who were in favour of only soft protection options identified the negative impacts that hard coastal protection options would bring to coastlines including, as they believed, the increased reporting of severe coastal erosion in islands as a result of implementing hard coastal protection measures.

To understand the different coastal protection techniques commonly used in the RoM, participants were provided a list of coastal protection measures and requested to identify the common measures they were aware of. The most commonly used measures in the country as identified by the participants were breakwaters, revetments, reclamation, beach nourishment, and sea walls. Twelve and thirteen percent of the participants identified that groynes and gabions are used in the RoM. About 12% of the participants identified other types such as artificial reefs and embankments are also used in the RoM. Vegetation was only identified by 2% of the participants. Figure 6-4 shows the common coastal protection measures in the RoM identified by the participants.

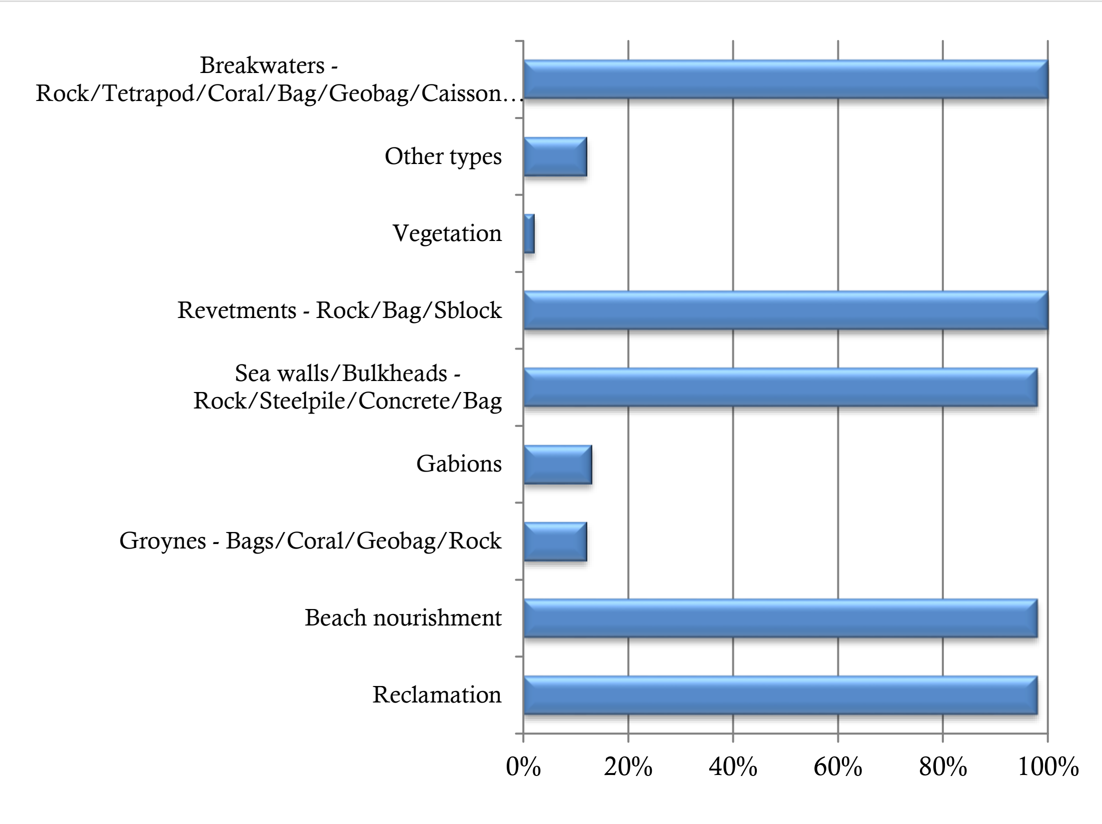


Figure 6-4 Proportion of professionals who identified different measures as a common type of protection in RoM.

In terms of the most common types of sea walls and bulkheads used in the RoM, concrete sheets were identified as the most frequently used type, sheet piled walls and rock armours the second, and sand cement bags a very close third (Figure 6-5). Less participants identified concrete caisson walls as a common type of seawall in the RoM.

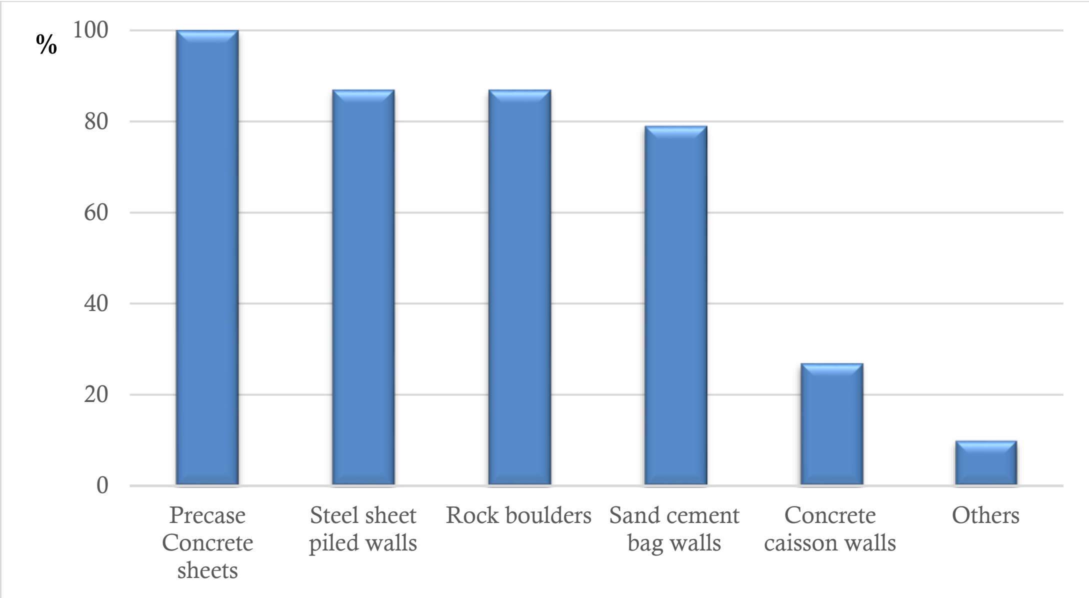


Figure 6-5 Distribution of professionals by types of sea walls and bulkheads identified as common in RoM

About half of the participants believed both groynes and gabions would work as effective coastal protection measures, although, they are 'less aesthetically appealing' over other techniques. Over 95% of the participants agreed artificial reefs could be a successful coastal protection measure despite the technique not being tested yet in the reef environment of the RoM. However, they were concerned that the measure would be expensive to implement or incompatible to the country's reef island environment. Participants identified embankment as a temporary measure, and believed it would not work alone in a typical coastline of the RoM. Majority of the participants believed beach ridge construction and vegetation would not be suitable techniques for the RoM except when they are combined with hard coastal protection measures because the coasts are too narrow, and the coastal wave climate of the RoM is too severe for such measures to work independently. Soft coastal protection options such as reclamation and beach nourishment are identified common coastal protection measures used in the RoM, however, 33% of the participants found they are not viable coastal protection measures for coastlines facing severe erosion unless combined with a hard protection measure. If faced with a choice between aesthetics and resiliency of measures in deciding a coastal protection option, over 90% of the participants claimed they would choose resiliency over aesthetics. However, as tourism is the country's main industry about 8% participants stressed the importance of having measures that are both resilient and aesthetically appealing.

Records from one of pioneering coastal contractor and one of the leading contractors in the RoM, the Maldives Transport and Contracting Company Plc (MTCC) acknowledged steel sheet piling projects have declined in the RoM (MTCC, 2014). Majority of the participants believed the main reason for this was the incompatibility of steel sheet piles to the harsh marine environments of the RoM that escalated maintenance issues in some projects, while a quarter of the participants believed the reason was purely economical, pointing out the rapid increase in steel prices. Other possible reasons identified include declining number of port projects in the RoM, and the technological advancements that made it possible for concrete piles to be used in deeper waters as an alternative to sheet piles.

6.3.4 Multi-hazard risks

The Environmental Protection Agency (EPA) received reports of severe coastal erosion from 85% of the inhabited islands and 45% of resort islands (UNDP, 2013). Although UNDP (2006) acknowledged coastal erosion was one of the hazards to the RoM, it disregarded coastal erosion risk in their multi-hazard risk identification exercise in DIRAM study. A number of professionals identified coastal erosion as a secondary hazard and expressed that coastal erosion itself becomes a hazard once triggered by another multi-hazard. However, a number of studies conducted on the subject of coastal protection have identified coastal erosion as a primary hazard which is also one of the most concerning hazards when it comes to coastal protection (Beca, 2010).

Discussions with professionals in the environmental sector suggest that the major hazards usually identified are so identified according to an environmental vulnerability context and are taken to be primary causes of vulnerability, while they view coastal erosion as a result of these hazards or as a secondary hazard.

Structural modifications to coastlines were the perceived cause for aggravated coastal erosion in some areas (Dias et al., 2003). While over 80% of the participants claimed witnessing cases of intensified coastal erosion after structural modifications to coastlines, they believe that the effects cannot be solely attributed to the measure. Instead, the use of inadequate designs, or application of inappropriate construction methods and materials, or disregard for coastal processes or a combination of these factors may be culpable. Figure 6-6 indicates the main factors that were believed to be the causes of coastal erosion in RoM.

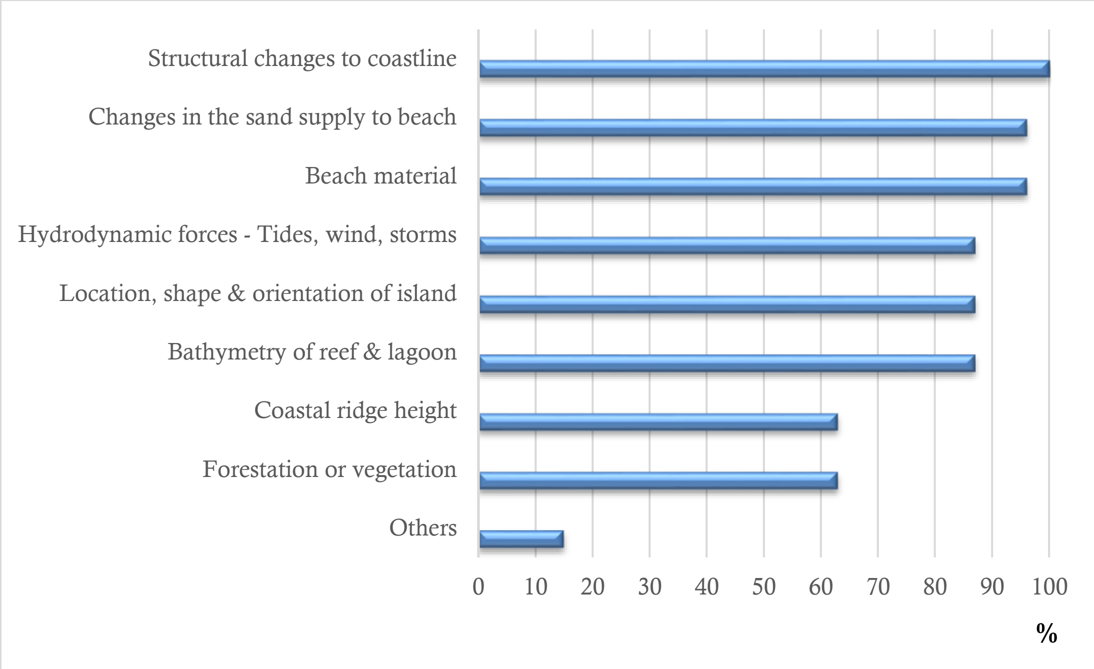


Figure 6-6 Distribution of professionals by views on main causes of coastal erosion in the islands

Structural changes to coastline, changes to the sand supply, and the type of beach material were identified as the most likely causes of coastal erosion by almost all participants, while a large majority agreed that hydrodynamic forces, bathymetry of the lagoon area and reef flat (the location and proximity of the coast respective to the reef, and depth of lagoon and how these factors contribute to erosion), and island specific features such as location, shape and orientation were causes. Forestation and vegetation, and coastal ridge height were less commonly believed to impact coastal erosion. Other factors identified include human interventions on the coastline, changes in weather patterns, and disregarding coastal processes in designs.

Participants were asked if Sea Level Rise (SLR) is a threat to the existence of the islands, as IPCC, in their 5th report (IPCC-AR5), estimated a global SLR of nearly 1m for the next 100 years. Over 70% of the participants believed SLR is a fact and it would be a threat to the existence of nations like the RoM. However, 19% of the participants believed there is no threat as the rate of SLR is slower than what IPCC has projected, and 10% of the participants believed there is no data backing the argument and considered SLR a myth.

6.3.5 Evaluation Aspects

Given that the main evaluation aspects identified were technical viability, hazard resiliency and socio-aesthetics and environmental acceptability, it was important to identify evaluation factors in each aspect. Participants were provided with two sets of factors for (1) technical viability and (2) socio-aesthetics and environmental acceptability as identified in the literature review, to assess the relative importance of these factors within their aspect. The factors were scored on a scale of 0 (Not Applicable) to 3 (Important) and then averaged. Figure 6-7 and 6-8 indicate the average scores that the factors received for technical viability and socio-aesthetics and environmental acceptability respectively. Since the DIRAM study identified the potential multi-hazards to the country and calculated the risk of different hazards, participants were not asked to assess the multi-hazard risks.

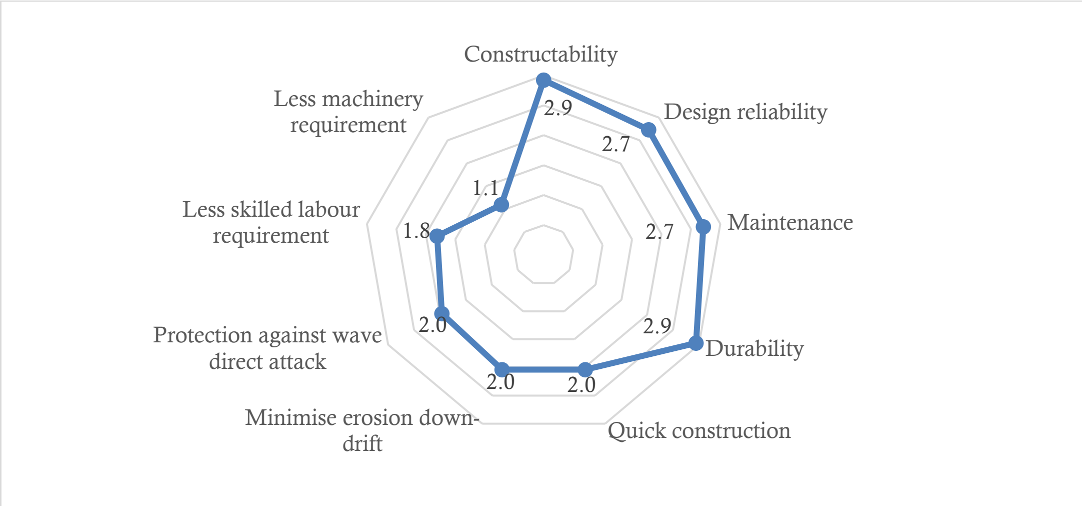


Figure 6-7 Average weight of Technical Viability evaluation factors, as weighted by professionals

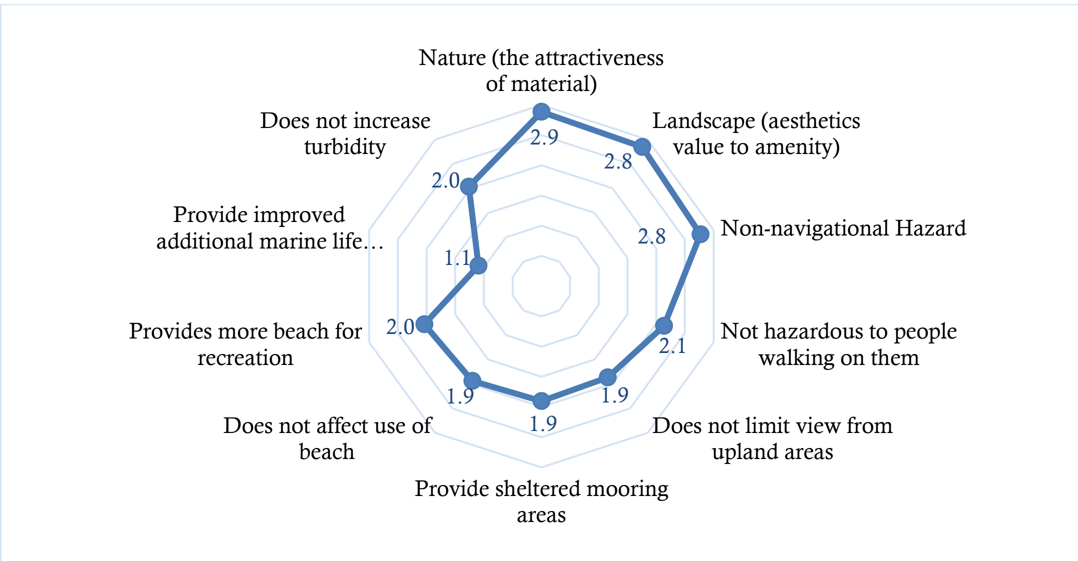


Figure 6-8 Average weight of Socio-aesthetics and Environmental Acceptability evaluation factors, as weighted by professionals

Participants were further asked to evaluate the common coastal protection measures in Figure 6-3 against the three sets of factors (technical viability, multi-hazard resiliency, and socio-aesthetics and environmental acceptability) by evaluating the performance of each measure against each of the factors on a scale of 0 (very poor) to 3 (good). Scores obtained thus were then averaged across participants. Figures 6-9, 6-10, and 6-11 shows the performance of the most common measures against technical viability factors, resiliency against multi-hazards, and performance against socio-aesthetic and environmental acceptability factors respectively. Finally, Table 6-2 shows the overall performance of the measures in each of the three categories when individual factor scores in Figure 6-9, 6-10, and 6-11 are averaged over all the factors in the respective category.

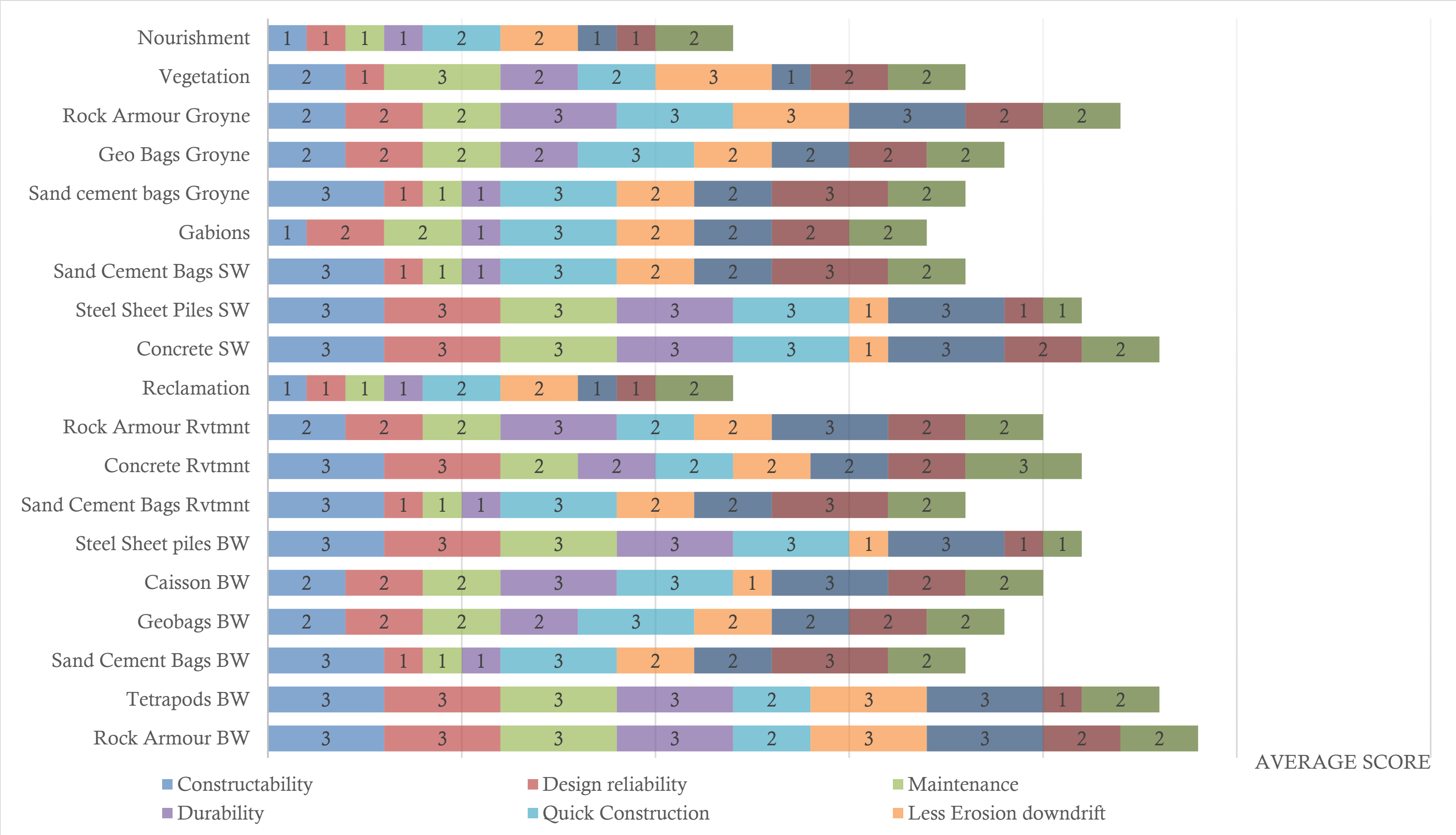


Figure 6-9 Average scores given by professionals for various measures, against the evaluation factors for Technical Viability. Sum of the factor scores for each measure gives the total Technical Viability score for that measure.

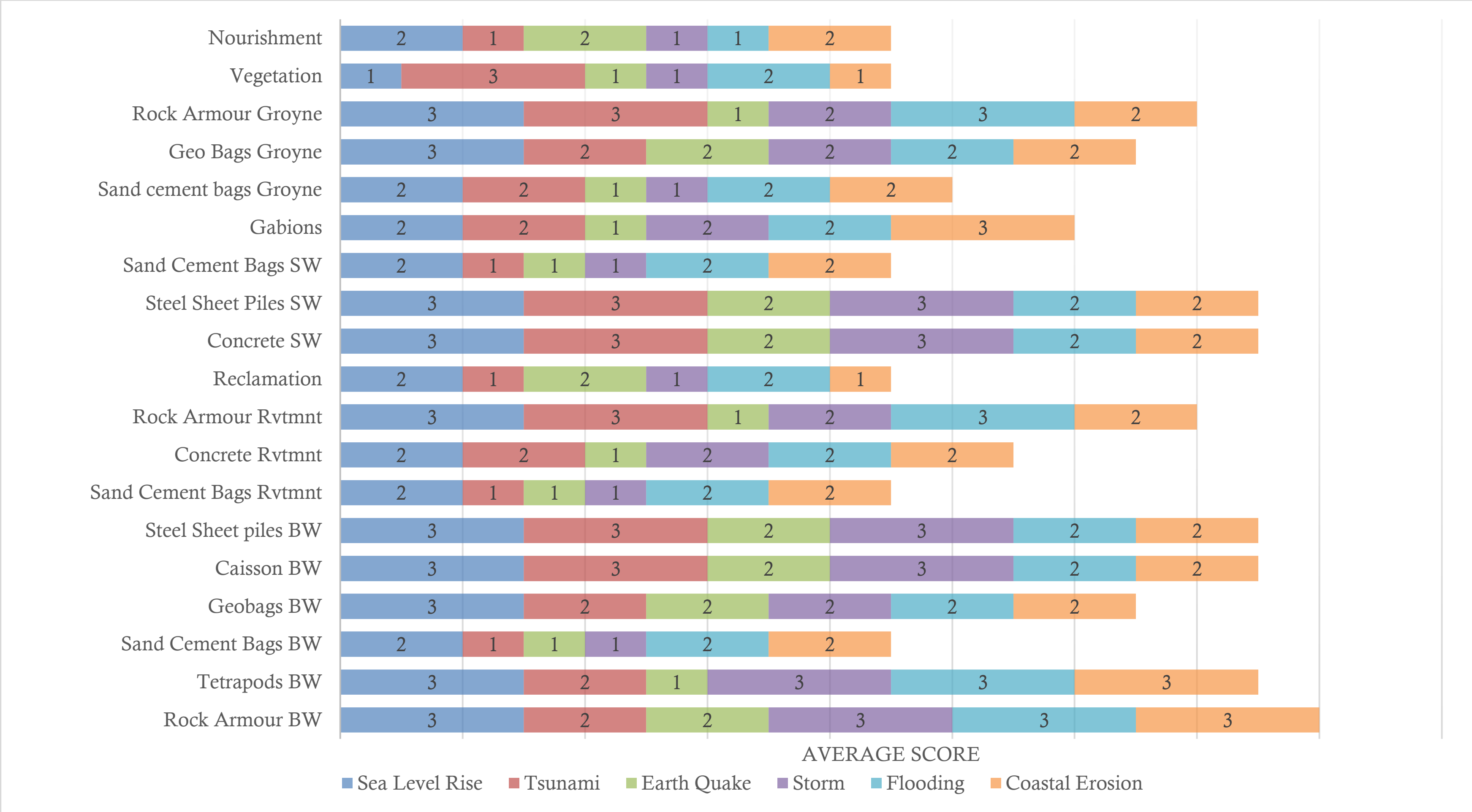


Figure 6-10 Average resiliency scores given by professionals for various measures for different hazards in the Multi-Hazard Resiliency parameter. Sum of the individual hazard resiliency scores for each measure gives the Multi-hazard resiliency score for that measure

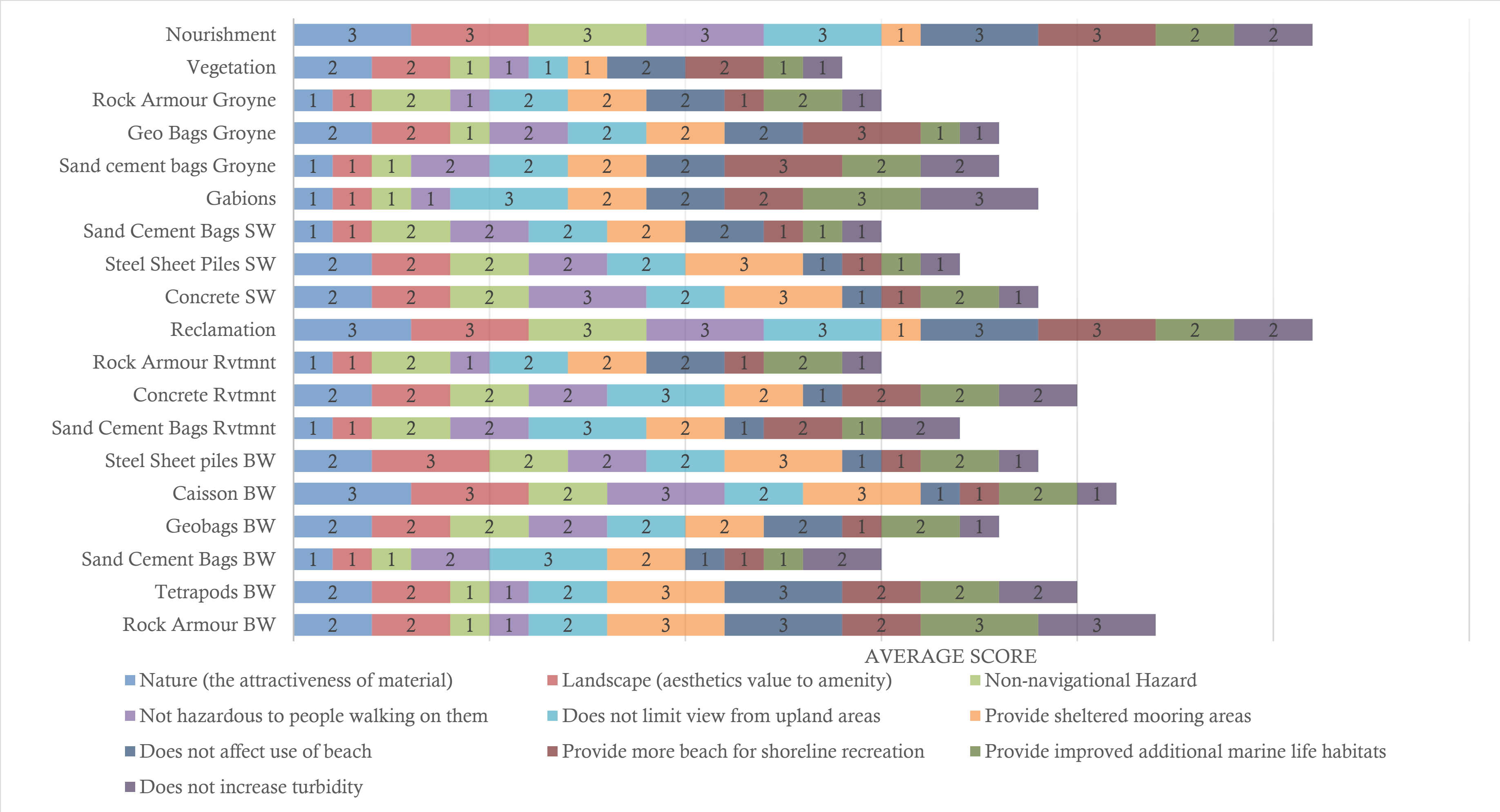


Figure 6-11 Average scores given by professionals for various measures against the evaluation factors for Socio-aesthetic and Environmental Acceptability parameter. Sum of the factor scores for each measure gives the total parameter score for that measure.

Table 6-2 Overall performance of the measures in the three evaluation categories.

Measure	Average score for		
	Technical viability	Hazard resiliency	Socio Aesthetics and Environmental Acceptability
Rock Armour BW	3	3	2
Tetrapods BW	3	3	2
Sand Cement Bags BW	2	2	2
Geobags BW	2	2	2
Caisson BW	2	3	2
Steel Sheet piles BW	2	3	2
Sand Cement Bags Rvt	2	2	2
Concrete Rvt	2	2	2
Rock armours Rvt	2	2	2
Reclamation	1	2	3
Concrete SW	3	3	2
Steel Sheet Piles SW	2	3	2
Sand Cement Bags SW	2	2	2
Gabions	2	2	2
Sand cement bags Groyne	2	2	2
Geo Bags Groyne	2	2	2
Rock Armour Groyne	2	2	2
Vegetation	2	2	1
Nourishment	1	2	3

Rock armour breakwaters, tetrapod breakwaters, and concrete seawalls are identified as highest scoring measures with 8 points for each. All the three measures scored highest in technical viability and multi-hazard resiliency aspects. The second highest with 6 scoring points are caisson breakwaters, steel sheet pile breakwaters, and steel sheet piled seawalls. All the three measures scored 2 in technical viability and socio-aesthetics and environmental acceptability aspects, and 3 in the multi-hazard resiliency aspect. Reclamation and nourishment scored highest in the socio-aesthetics and environmental acceptability but achieved low scores in technical viability aspect.

6.4 CHAPTER SUMMARY

This chapter presented findings from interviews conducted with coastal protection industry professionals including contractors or consultants, policy level staff from relevant government institutions, key professionals from local islands. The results identified the most common types of coastal protection measures in the RoM, professionals' views on coastal management policies, multi-hazard risks and the need for and design of DSFs for coastal protection decision making. The key parameters and factors for evaluating protection measures, initially identified through the literature review, were confirmed with the professionals to validate their applicability to the DSF. Factor weights were derived through participants' assessment of their importance in the evaluation process and their evaluation of different protection measures against the identified evaluation factors was also obtained. In the next chapter, these parameters and evaluation factors are used in addition to literature review in constructing the evaluation stages of the DSF.

7 THOSHI COASTAL PROTECTION DECISION SUPPORT FRAMEWORK

7.1 INTRODUCTION

As discussed in previous chapters, the main goal of this research is to devise a simplified and structured DSF to facilitate professionals working in the coastal protection area to evaluate and select appropriate coastal protection measures for the RoM. THOSHI presents step by step guidance from the stage where the problems are identified until appropriate measures are shortlisted for the decision makers to select from. It facilitates the decision makers to systematically evaluate various coastal protection measures on both technical and financial aspects, and select appropriate measures based on their cost-benefit analysis.

THOSHI has seven stages: 1) define coastal protection problem; 2) determine policy options and identify the desired action(s); 3) identify feasible measures; 4) technical evaluation of feasible measures; 5) financial evaluation of feasible measures; 6) conduct cost-benefit analysis on shortlisted measures (optional); and 7) stakeholder validation and selection of appropriate measure(s) (Figure 7-1). Stakeholders need to work with specific guidance from experts/engineers during stages 1 and 2 to determine the coastal protection problem and decide on an action to follow depending on the problems identified. Stages 3 to 6 are then used to evaluate feasible measures that are identified at the end of stage 2.

This chapter describes the stages of THOSHI and explains the steps involved. Firstly, it highlights the stages one and two to define the coastal protection problem. Secondly, from stage 3 to 5 it describes the evaluation process. Finally, it provides information on the stakeholder validation and selection of appropriate measures.

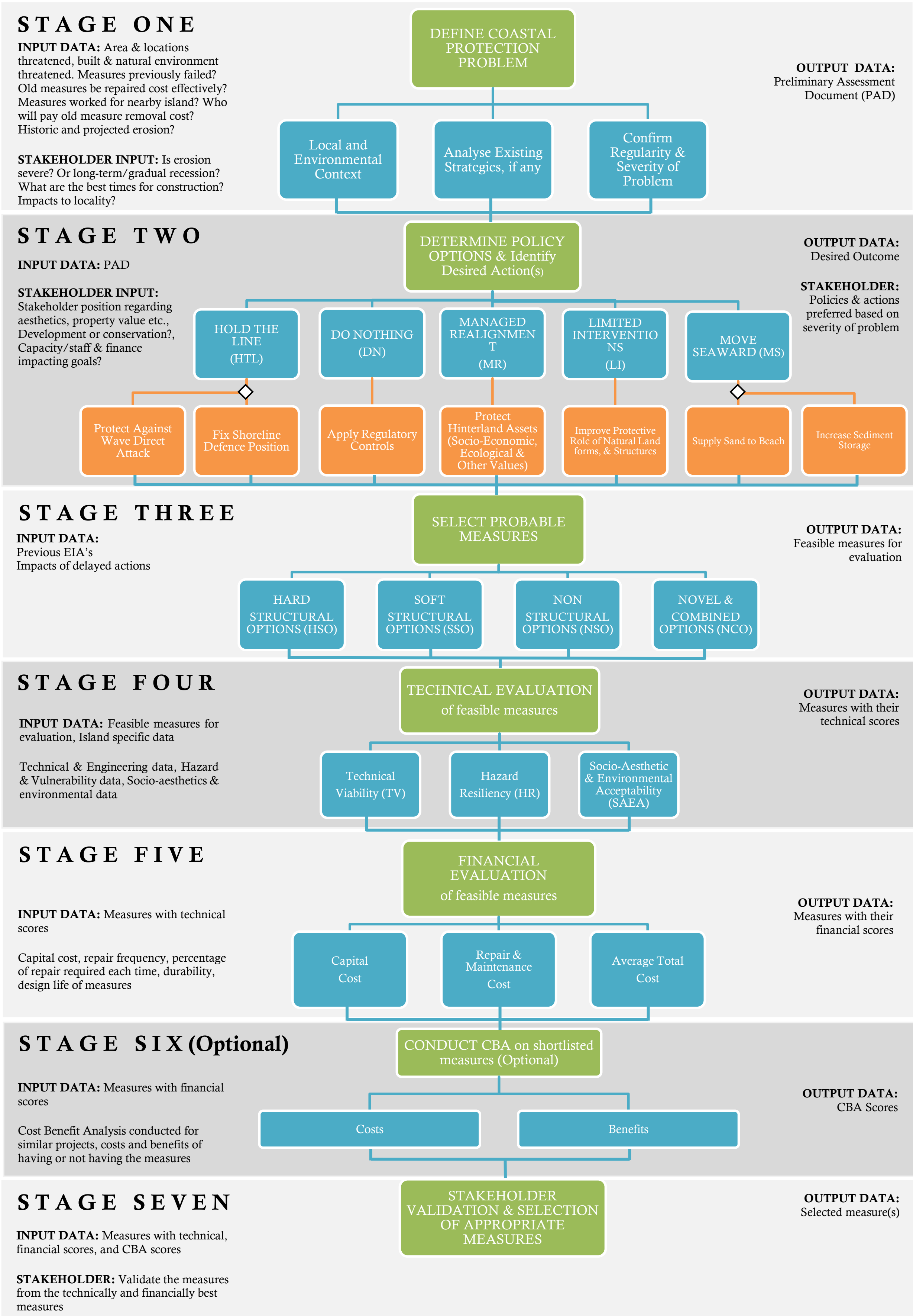


Figure 7-1 THOSHI Coastal protection decision support framework

7.2 Stage 1: Define Coastal Protection Problem

The main objective of the problem definition stage is to get to know the root cause of the problems for informed decision making. This stage has three steps: (1) understand local and environmental context, (2) analyse existing strategies, and, (3) confirm regularity and severity of the issue(s). Specific problems to the site must be clearly identified and understood in this stage. The steps involved in this stage are presented and discussed.

The first step is to understand the local and environmental context. Deciding on a required action depends mostly on the comprehensiveness of the information gathered at this stage. Therefore, it is important to collect as much information as possible on areas such as geological conditions, topographical and maritime conditions, and tide generation and current data. Some of the important information that needs to be addressed in this stage are the type of coastline (e.g. rocky, coral or sandy beach), the type of coastal processes (e.g. high energy waves and currents), area of sediment accretion indicating the flow direction of longshore sediments, evidence of coastline and scarp erosion, beach elevation, grain size (e.g. large or small), presence and location of beach rock, coastal vegetation cover and types, and, local drainage patterns such as natural runoff or storm water (Beca (2010). In addition, area affected and threatened built and natural resources are important information required for this step.

The second step is to confirm the severity and regularity of the issue. Local stakeholder collaboration in this stage is paramount as J. Dronkers et al. (1990) found that there are no formal records of island-specific coastal changes recorded in the RoM, and the survey presented in Chapter Six identified that the local stakeholders are the most informed people with regard to the issues related to their local coastlines. Local stakeholders could identify erosion and inundation impacts to their communities, and establish their desired outcome from measures proposed for the coastline protection. 'It is also important to determine whether the coastal erosion is occurring over the short or long term as erosion over the short term is not likely to require any action whereas long term erosion will require some action' (Beca, 2010).

Additionally, information such as historic and projected erosion trends, the best time of the year to implement such works, and the constraints for work implementation at the site are information that the stakeholders would know best. Other information, such as the urgency and the need for coastline protection for the site, and how large of an area is under threat is vital information that need to be collected in this stage.

The final step is to analyse various protection measures implemented for the site, other parts of the same coastline and the nearby islands help to identify the type of measures that may be suitable for such locations. The data gathered in this stage will also contribute to establish the resiliency and effectiveness of such measures, the reasons for failure, and whether the measures can be repaired cost-effectively. If the existing structures need to be removed, the financial cost of removal and the socio-aesthetics and environmental cost of removal or doing nothing should be considered. The condition of the structures, the materials used, the signs of damage or failure, and sign of regular overtopping by inspecting the land behind the structure(s) is important information for this stage (Beca, 2010).

Once the coastal protection problems and their causes are understood, a Preliminary Assessment Document (PAD) will be generated detailing the findings. This document will become an input for Stage Two where the policy makers and stakeholders could use it to identify the underlying problems, previous actions and other important data relevant for them to make an informed decision.

7.3 STAGE 2: DETERMINE POLICY OPTIONS AND IDENTIFY DESIRED ACTION(S)

Stage two has two steps: (1) determine policy options, and (2) decide on the desired actions to follow. Mcglashan and Williams (2003) found that the understanding of physical changes to coastlines and their impacts on stakeholders in a coastal environment ultimately improves the quality of decision outcomes. Therefore, local knowledge of the stakeholders, the experience and understandings of the experts, and the qualitative judgment of other decision makers could be pooled to identify policy options within the five coastal protection and management policies adapted for Eurosion guide (1. Hold the line, 2. Do nothing, 3. Managed realignment, 4. Limited intervention, and 5. Move seaward) (Salman et al., 2004). When the policy is decided, an action or actions preferred can be identified to recognise the feasible measures for evaluation (McCue et al., 2012; Salman et al., 2004).

Local stakeholder involvement in the policy selection stage will help to identify stakeholder position with regard to aesthetics and property value, stakeholder's priority (development or conservation), local availability of resources, and other constraints that may need to be addressed in achieving a workable solution. The set of actions that are available for each policy may differ according to geographical context. However, for the purpose of THOSHI, the set of 'actions to solve the problems' identified in (McCue et al., 2012)and Salman et al., 2004 are adapted.

The Preliminary Assessment Document (PAD) generated at the end of Stage One, among other sources of information, will be an important data input in this stage and will assist the stakeholders and decision makers in selecting the relevant policy option and the actions to go forward with.

This stage is also the first impression and the most basic remedies to solve the problems identified in Stage One. If the PAD identified erosion is acute and the coastline degradation can have long term impact on normal coastal processes, policies that encourage less structural options are preferred (e.g. do nothing, and limited intervention). On the other hand, if the erosion is chronic and undercutting, and the events are frequent, policies that support defending the coastline and hinterland assets are preferred. However, if the frequency is moderate or low when the severity is still high, both hard and soft structural options can be explored. In a situation where an existing measure is in place, its performance may be evaluated first. Existing measure that have failed, did not withstand the existing environmental conditions, and are found non-resilient to the existing wave climate can be removed from the probable measures list. However, existing measures that have not completely undermined or are found to be resilient when combined with other measures could be included in the probable measures list. Table 7-1 summarises the policies and the possible actions for each policy.

Table 7-1 Main coastal protection Policy options and corresponding actions for that policy (adapted from McCue et al. (2012) and Salman et al., (2004))

Policy	Actions
Hold the line (HL): HL encourages maintaining the existing coastline in position. If an existing measure is in place it has to be maintained or changed to more resilient type to hold the existing defence line. HL also allows additional measures to be erected in front (seaward) of the existing defence line. Measures erected landward to the existing defence line can also be considered HL if they formed an important part of protecting and maintaining present line of defence and have the capacity to halt erosion (Banton et al.)	***Protect against wave direct attack:*** This action uses measures that stop the waves from directly attacking the coastline; hence it becomes first line of defence and in the RoM context of coral reef islands, this usually applies far shore or near shore. Measures that are capable of withstanding high wave pressure and absorb or diminish wave energy are encouraged. Hard Structural Options (HSO) and Novel or Combined Options (NCO) are therefore recommended. Soft Structural Options (SSO) are typically not applicable for this action in the RoM context. ***Fixing coastline defence position:*** This action uses measures that hold the coastline in its position regardless of other impacts to other parts of the coastline. Measures under HSO and NCO are therefore recommended.
Managed Realignment (MR): MR requires deliberate breaching of existing coastal protection with the adjacent land consequentially being flooded, and needs additional inland areas for the lives and livelihoods in that area to be relocated **(Luisetti et al., 2011)**. This is because the existing measures are either too costly to maintain or less beneficial to the local community. A new line of defence could be installed landward to the original line of defence under this policy.	***Protect hinterland assets***: Protecting hinterland assets are the main priority under this action. Non-Structural Options (NSO) can be used to either abandon the existing structures or relocate the lives and livelihoods to an inland area or another island. In some cases, measures under HSO could be used landward to the existing line of defence. NCOs could be applicable when such novel approaches emerge.
Move seaward (MS): In areas where flooding, erosion and overtopping hinder the use of infrastructure and other inland amenities, MS is encouraged. Also, to cater for the growing population and development demands in potential islands MS is a common approach to increase land area in the RoM. New lines of defence are generally required seaward of the new coastline under this policy.	***Increase sediment storage***: This action allows sediment to be deposited in order for the coastline to grow big and move seaward (e.g. HSO – Groynes). This action may not be considered for areas that require quick filling or the coastline is too close to the reef edge. NCOs could be applicable when such novel approaches emerge. ***Supply sand to beach***: This action requires fill material to be supplied from elsewhere to the beach. Measures within Soft Structural Options (SSO) and NCO are commonly used. NCOs could be applicable when such novel approaches emerge.
Limited Intervention (LI): LI attempts to slow down the coastal process rather than forcing it to stop completely. Therefore, LI is generally not recommended to areas where wave action is strong.	***Improving protective role of natural land forms, structures or features:*** This action requires measures to be used to improve and support the existing coastlines thus massive coastal protection measures are not generally used. NCOs could be applicable when such novel approaches emerge.
Do nothing (DN): Any physical protection measures are discouraged, thus no investment in coastal defence assets or operation is required in this policy.	***Regulatory controls***: This action requires no physical coastal protection measures, but regulatory means to mitigate against climate change issues (e.g. setbacks, no development zones etc.).

7.4 STAGE 3: SELECT PROBABLE MEASURES

When the actions are finalized, each action would then lead to a set of protection measures from which the probable measures can be selected. The measures commonly used in the RoM can be classified into four different categories: Hard Structural Options (HSO), Soft Structural Options (SSO), Non-Structural Options (NSO), and Novel or Combined Options (NCO) (Table 7-2).

Table 7-2 The four categories of coastal protection options used in the RoM

Hard Structural Options (HSO):	It is generally a policy of 'defend at any cost' whereby hard engineered measures would be constructed to provide existing or improved levels of protection regardless of the changing sea level or wave climate (Leafe et al., 1998). These options are sometimes categorised according to their purposes (MHE, 2011b). Erosion control and prevention: (foreshore seawalls/bulkheads, nearshore breakwater, revetments, groynes), Access infrastructure: (breakwater, quay wall, groynes, jetty), rainfall flood mitigation (artificial wetland drainage, temporary drainage, roads), and Other options (causeways, bridges). From the categories above, this thesis focuses on the 'erosion control and prevention measures', which is the most commonly used category of coastal protection in the RoM (MHE, 2011b)
Soft Structural Options (SSO):	These are soft coastal protection measures that generally help to retain the natural features. These options are sometimes categorised according to their purposes. 'Quick fix measures (e.g. beach replenishment) and Long term measures (e.g. coastal vegetation retention and reclamation' (MHE, 2011b).
Non-Structural Options (NSO):	This option encourages the coastline to establish its natural position by either abandonment of existing structures or use of regulatory controls. The inevitable consequences of this option may include the abandonment of coastal dwellings and buildings, and the loss of farmland and infrastructure (Leafe et al., 1998).
Novel or Combined Options (NCO):	These are technological advancements or mix of hard and/or soft measures used to eliminate issues or improve the benefits of hard and/or soft measures application. A combination of two or more measures can help mitigate the weaknesses of installing one distinct type of measure. 'A combination of hard measures (detached breakwaters and slope protection) and soft measures (beach nourishment to fill up the bays behind the detached breakwaters to the equilibrium profile) executed in Hyllingebjerg was found to be very successful that it created a stable coastline, widened recreational beaches, protected the houses on the cliffs and an increased the aesthetic view of the coast' (Salman et al., 2004). Because of the inadequacy of some of the soft measures in the RoM context, these measures are generally replaced with hard measures at some point. An example is *Gulhifalhu* project, where the lagoon was reclaimed to provide residential housing and warehousing for the greater Male' area. When the reclaimed area faced severe erosion, the authorities realised that reclamation alone was not sufficient to stop the erosion, thus Geobags were installed as an embankment protection.

This section describes the pathways to select probable measures for each policy options selected. As described above the policies selected will lead the users to choose actions to solve problems, and that will lead to the possible coastal protection options. Finally, the probable measures will follow depending on the options chosen. Table 7-3 shows the pathways to probable measures for the five policies used in THOSHI.

Once the probable measures are selected, they will be evaluated both technically and financially to find out feasible measures. The next stage describes the parameters and the factors used for evaluation.

Table 7-3 Pathways to selection of probable measures starting from policy selection

Policy	Action	Type of measure			
		HSO	SSO	NSO	NCO
HL	Protect against wave direct attack	Offshore BW, SW, Revetment, Gabions	NA SSO's may not withstand to strong wave attacks hence are not applicable	NA NSO's are not recommended in areas where the coastline is subjected to wave attack	Offshore Breakwater+ Seawall, Offshore Breakwater + Revetment, Offshore Breakwater + Gabions, Seawall + Revetment, Seawall + Gabions
	Fix coastline defence position	Seawalls, Revetments, Gabions	NA SSO's are generally not capable of fixing the coastline position.	NA Fixing coastline in position requires structural means hence NSO's cannot be applied.	Seawall + Revetment, Seawall + Gabion
MR	Protect hinterland assets (socio-economic, ecological & cultural values	Seawall	NA	Relocation	Possible NCOs to be decided
MS	Increase sediment storage	Groynes	NA	NA	Possible NCOs to be decided
	Supply sand to beach	NA	Reclamation, Beach Nourishment	NA	Groynes + Beach Nourishment, Revetments + Beach Nourishment, Seawall + Beach Nourishment, Reclamation + Seawall, Reclamation + Revetment
LI	Improve protective Role of Natural Land forms, Structures or features	NA	Vegetation management (Marsh or Riparian Buffer)	NA	Possible NCOs to be decided
DN	Regulatory Controls	NA	NA	Land use controls, Setbacks	NA

7.5 STAGE 4: TECHNICAL EVALUATION OF FEASIBLE MEASURES

The objective of this stage is to evaluate probable measures on multiple decision parameters by weighting the technical factors that constitute them. In the technical evaluation, the measures that come up with the highest scores are considered more feasible and vice versa. The parameters identified for Technical Evaluation are (1) technical viability (TV), (2) multi-hazards resiliency (MHRE), and (3) socio-aesthetic and environmental acceptability (SE). To determine the parameter value for a given measure, a set of weighting factors for each parameter were identified based on the literature review, and the research conducted.

The policy makers and professionals' perception survey in Chapter 6 concluded that out of the three parameters of Technical Evaluation, TV is the most important parameter for the RoM. While decision makers can adjust the weights of the three parameters to fit the context to which THOSHI is applied, for the purposes of the case studies in this research, TV is given a weight of 70 percent.

7.5.1 Technical Viability (TV)

TV evaluates the factors related to engineering and technical aspects of coastal protection measures. Several factors were initially identified from the literature review (technical standards and other relevant engineering literature that examined the technical aspects of coastal protection measures), and later refined through the survey 'Professionals' Perspectives of coastal protection in the RoM', that need to be accounted for when evaluating TV. Factors are given individual weight (w) of 3 – 1 depending on their importance (i.e. 3 for the most important to 1 for the least important).

The most important factors regarding technical viability (constructability, design, maintenance, and durability) are given an individual weight of 3 to each factor. Factors such as quick construction, lack of increase in erosion down-drift, protection against direct wave action, and availability of materials are given an individual weight of 2. The requirement of less skilled labour, and the requirement of less machinery & equipment were found to be desirable but less critical factors, so a weight of 1 was given to each of these factors. Table 7-4 shows the TV factors selected and the weights for each factor.

Table 7-4 Evaluation Factors selected for Technical Viability with their individual weights

FACTORS (i)	WEIGHT (w)	REMARKS
1. Constructability	3	A primary consideration to be addressed as early as possible. Identifying measures through trial and testing are too costly for a country like the RoM, thus proven construction methods and measures that are easy to implement are vital.
2. Design: Reliability	3	Reliability of the design used can save a lot of time and money.
3. Maintenance: Simplicity of repair, visibility of faults	3	Maintenance includes simplicity of repair and sometimes the visibility of faults. Age of certain measures can be extended if repair and maintenance is done in an early stage.
4. Durability & design life	3	Measures are required to withstand a high degree of wave pressure and are always designed to have maximum life for the particular environment they are designed for.
5. Quick construction	2	In the RoM where the monsoonal climate sometimes allows only narrow window for construction works, construction time frames are vital.
6. Lack of increase erosion down-drift	2	Other areas of the coastline should not be eroded as a result of the measure implemented.
7. Protection against direct wave action	2	To protect the coastline, it is important that the measure acts as a barrier to stop waves from directly interacting with the coast.
8. Less skilled labour required	2	Measures that require less number of skilled labour are favoured. Acquiring skilled labour may incur unnecessary project delays.
9. Less machinery & equipment required	1	Acquiring machinery, especially complex machinery would be difficult. Measures that require less machinery are easy to implement.

A discrete scale of 0 to 3 is given to feasible coastal protection measures with regard to the weighting factors (i), where 0=very poor, 1=poor, 2=fair and 3=good. Thus, the maximum possible score for any factor will be 3 and the proportional score (*s*) will be the raw score divided by the maximum possible score, which is 3 according to the scale used in THOSHI. The weighted score(S) for the individual factor i is then obtained by multiplying the proportional score s by weight w (Eq. 1).

$$S_i = s_i \times w_i \,; \qquad \text{Eq. (1)}$$

$$where\ i = \{1 \ldots 9\}, corresponding\ to\ each\ individual\ factor$$

Thus, the Technical Viability Score (TV) for measure x is obtained by the sum of the weighted scores divided by the sum of weights.

$$TV_x = \frac{\Sigma S_i}{\Sigma w_i} \;\; ; \;\; i = \{1 \ldots .9\} \qquad \text{Eq. (2)}$$

Table 7-5 shows the factor raw scores given to the measures for individual factors and the resulting TV scores for each measure for THOSHI. The calculations for the measure Rock Armour BW is shown in the shaded cells.

Table 7-5 Technical viability scores for various measures

		Factor Raw Scores									***Total W, S***	**Technical Viability Score (TV)**	**TV weighted at 70%**
TECHNICAL CATEGORY	**Factor (i)** *weights* / **MEASURE (x)**	**(1)** *3*	**(2)** *3*	**(3)** *3*	**(4)** *3*	**(5)** *2*	**(6)** *2*	**(7)** *2*	**(8)** *2*	**(9)** *1*	*21*		
Breakwater	Rock Armour	3	3	3	3	2	3	3	2	2			
	proportional score(s)	*1*	*1*	*1*	*1*	*0.67*	*1*	*1*	*0.67*	*0.67*			
	Weighted scores (S)	*3*	*3*	*3*	*3*	*1.33*	*2*	*2*	*1.33*	*0.67*	*19.33*	0.92	64.44
	Tetrapods	3	3	3	3	2	3	3	1	2		0.89	62.22
	Sand Cement Bags	3	1	1	1	3	2	2	3	2		0.63	44.44
	Geobags	2	2	2	2	3	2	2	2	2		0.70	48.89
	Caisson	2	2	2	3	3	1	3	2	2		0.75	52.22
	Steel Sheet piles	3	3	3	3	3	1	3	1	1		0.84	58.89
Revetments	Sand Cement Bags	3	1	1	1	3	2	2	3	2		0.63	44.44
	Concrete	3	3	2	2	2	2	2	2	3		0.78	54.44
	Rock armours	2	2	2	3	2	2	3	2	2		0.78	54.44
Reclamation	Reclamation	1	1	1	1	2	2	1	1	2		0.41	28.89
Sea walls / bulkheads	Concrete	3	3	3	3	3	1	3	2	2		0.89	62.22
	Steel Sheet Piles	3	3	3	3	3	1	3	1	1		0.78	54.44
	Sand Cement Bags	3	1	1	1	3	2	2	3	2		0.63	44.44
Gabions	Gabions	1	2	2	1	3	2	2	2	2		0.60	42.22
Groynes	Sand cement bags	3	1	1	1	3	2	2	3	2		0.63	44.44
	Geo Bags	2	2	2	2	3	2	2	2	2		0.70	48.89
	Rock Armour	2	2	2	3	3	3	3	2	2		0.81	56.67
Vegetation	Vegetation	2	1	3	2	2	3	1	2	2		0.67	46.67
Beach Nourishment	Nourishment	1	1	1	1	2	2	1	1	2		0.41	28.89

7.5.2 Multi-hazard resiliency

The second parameter selected for the technical evaluation is multi-hazard resiliency (MHRE) of coastal protection measures to the most common hazards to RoM. Common hazards are identified through UNDP (2007) and UNDP (2006) since there is no other literature available that covers multi-hazards data in the RoM as extensively. These hazards are further refined in light of the literature review and the research conducted. The set of multi-hazard data on DIRAM studies (except the coastal erosion data) are used in this framework as it is the only available data set covering multi-hazards data for the islands selected for this study. Table 7-6 shows the major hazard categories identified by UNDP (2007), and hazards selected for this study.

Table 7-6 Different categories of hazards and hazards selected for use in THOSHI

Hazard category	Name of hazards (UNDP (2007))	Selected hazards for THOSHI
Geological	Earthquakes, Landslides, Coastal Erosion	Earthquakes, Coastal Erosion
Meteorological	Tropical Cyclones, Tropical Storm (Strong wind), thunder storm, and water spouts	Tropical Cyclones
Hydrologic	Storm surges, swell waves, *Udha*, tsunamis, heavy rain fall and drought	Tsunamis, Coastal Flooding (Storm surges and Swell waves)
Climate Change	Sea level rise, changes in precipitation, sea surface temperature rise, storm activity	Sea Level Rise

It is difficult to draw a line between the hazards, and categorization of hazards is often contentious and a considerable number of the hazards are inter-related (UNDP (2007). Hazards that have no direct impact on coastal protection measures, and are not very significant in the RoM case, are not considered in this study (e.g. landslides, thunder storms, water spouts, strong wind, heavy rain fall, drought, changes in precipitation, sea surface temperature rise). After careful literature search and the survey, the following hazards were selected for THOSHI: SLR, tsunamis, earthquakes (EQ), storms, coastal flooding, and coastal erosion. UNDP (2007) and UNDP (2006) identified that the types of hazards, frequency and severity are different in different parts of the RoM. UNDP (2006) identified that storm risks are highest at north and lowest at south, earth quake risk is highest at south and lowest at north, flooding risk moderate at east and increases towards west, and tsunami risk is highest at east and moderate towards west.

Coastal erosion is generally not taken as a primary hazard to the RoM, and the risks and vulnerability are not assessed in any of the reports in spite of the relevant government agencies confirming that over seventy percent of the islands face severe coastal erosion (MEE, 2015), and that it is impacting the lives and livelihoods significantly (McCue et al., 2012).

Discussions with professionals in the environmental sector suggest that the major hazards usually identified are so identified according to an environmental vulnerability context and are taken to be primary causes of vulnerability, while they view coastal erosion as a result of these hazards or as a secondary hazard.

According to UNDP (2007) 'coastal erosion is generally considered a consequence of sea level hazard exposure' and its impacts are exacerbated due to changes in climate. However, Boruff et al. (2005), Jana and Bhattacharya (2013) and Mujabar and Chandrasekar (2013) considered coastal erosion as a major hazard. Therefore, in the context of this study where a primary reason for coastal protection measures is the hazard of coastal erosion, it justifies taking erosion as a primary hazard. Figure 7-2 shows the qualitative model of physical environment and hazard interaction from DIRAM study.

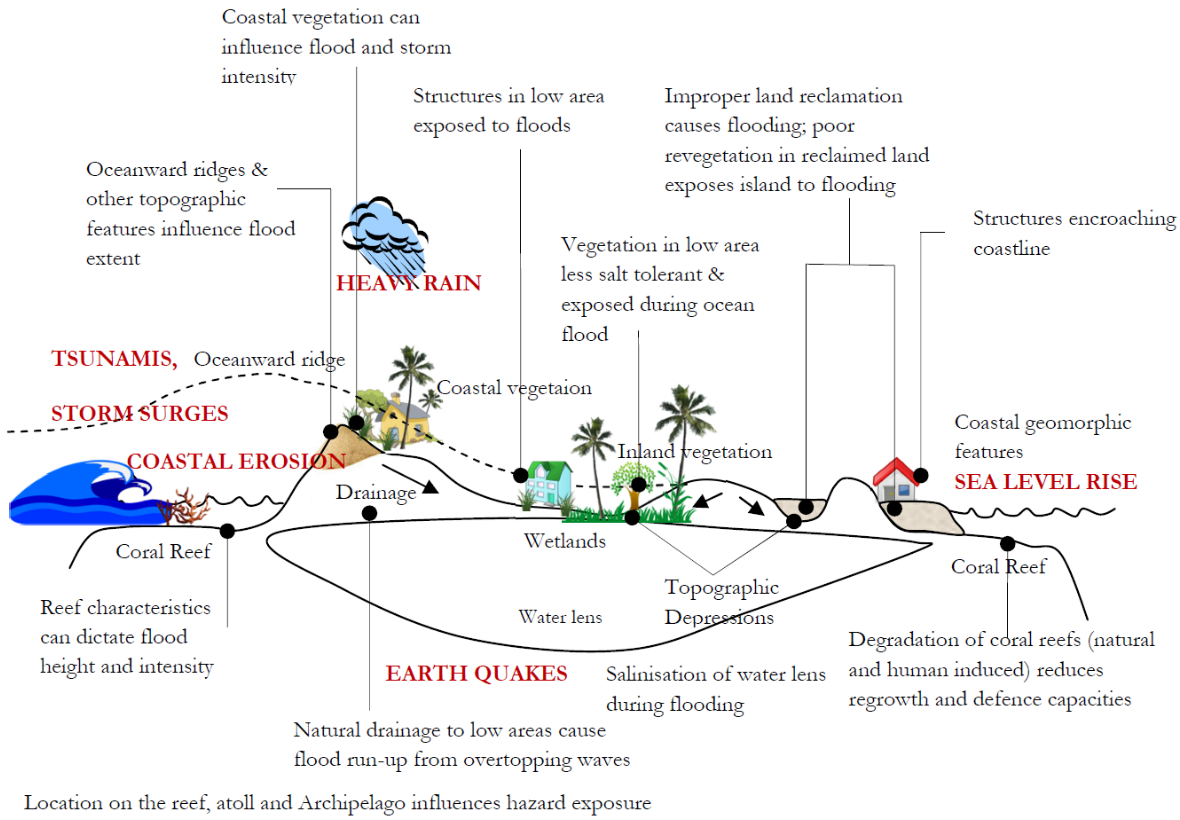


Figure 7-2 Qualitative model of hazards and key natural environmental impacts in the RoM (adapted from (UNDP, 2007))

Various guidelines and manuals elsewhere such as (Salman et al., 2004), USACE (2003), and Wratt et al. (2004) strongly recommend coastal erosion as an important hazard to be combated in coastal protection. Since coastal erosion is not generally investigated as a primary hazard in the RoM, hazard risk indices for coastal erosion were unavailable. This necessitated a review to find out the major determinants of coastal erosion so that island-level hazard risk scores could be obtained by evaluating these determinants or factors. The major factors that contribute to the risk of, or the damage from, coastal erosion that were identified through literature review are listed in Table 7-7. Some factors like existence of *Forestation and Mangroves* would lower the erosion hazard risk while factors like extent of *Sand Extraction* would likely increase the risk (EPA, 2014). These are the factors that will be used to evaluate hazard risk from coastal erosion for THOSHI.

Table 7-7 A literature review of factors that contribute to Coastal Erosion

Contributing factors	Reference
Forestation and mangroves	McCue et al. (2012), Salman et al. (2004)
Hydrodynamic forces (tides, winds and storms)	USACE (1984,1995,2003), Cummings et al. (2012); Swan River Trust (2009), UNDP (2007)
Bathymetry (Reef flat and lagoon)	McCue et al. (2012), Salman et al. (2004), UNDP (2007),
General beach material	Salman et al. (2004), UNDP (2007)
Ridge height	McCue et al. (2012), Cummings et al. (2012), Scott et al. (2013), UNDP (2007)
Modifications to coast	McCue et al. (2012), USACE (1984,1995,2003), , Dupray et al. (2010), Salman et al. (2004),
Sand extraction	Salman et al. (2004), UNDP (2007)
Location, shape and orientation of island	McCue et al. (2012), Salman et al. (2004), UNDP (2007)

Based on the above contributing factors, and the geo-physical data from the islands obtained through focus group discussions and site visits, the above factors were given a score from 0-3 (where 0=very low, 1=low, 2=fair and 3=high) according to how the factor increased or decreased the coastal erosion hazard risk for that island. A final Hazard Risk for Coastal Erosion (HRCE) is derived by averaging these scores. Table 7-8 shows the HRCE values for survey islands using the factors in Table 7-7.

Table 7-8 Calculation of Hazard Risk for Coastal Erosion(HRCE) for the survey islands

ISLANDS	Hydrodynamic forces (tides, winds and storms)	Forestation and mangroves (Vegetation belt width)	Coastal Ridge Height (Ocean Ward) (m)	Coastal Ridge Height (Lagoon Ward) (m)	Bathymetry (Reef flat and lagoon width)	General beach material	Shoreline modifications	Sand extraction (mining)	Location, shape and orientation	**Final HRCE**
HDh. Kulhudhuffushi	3	1	1	3	1	2	3	2	2	**2**
Sh. Funadhoo	3	3	1	3	3	1	2	1	2	**2**
K. Thulusdhoo	3	3	2	3	2	2	3	3	2	**3**
Dh. Kudahuvadhoo	2	2	2	3	1	2	1	2	1	**2**
Th. Vilufushi	2	2	2	3	1	2	3	0	2	**2**
L. Gamu	2	2	2	3	2	2	2	3	2	**2**
Ga. Villingili	2	3	3	3	2	2	2	3	3	**3**
GDh. Thinadhoo	1	2	2	3	1	2	3	1	1	**2**
S. Feydhoo	1	3	2	3	1	2	3	3	1	**2**
S. Hithadhoo	1	3	1	3	2	2	3	3	1	**2**

The first step in calculating multi-hazard resiliency is to calculate island level Hazard Risk scores. The DIRAM study, (UNDP, 2007) gives a general hazard risk mapping for the whole of RoM showing how risk increases going east to west and north to south. UNDP (2006) calculates a Hazard Risk Index for all the islands in RoM and additionally divides the RoM into five hazard regions according to the hazard risk for each hazard except coastal erosion. In general, except for flooding, both mappings match for Tsunami, Earthquake and Storm/Cyclone Hazard. Due to the unavailability of raw data from the study, the exact Hazard Risk Index for the surveyed islands were unobtainable from the (UNDP, 2007) study. Thus, the geographical hazard risk maps for Earthquake, Tsunami and Cyclone (Storm) from the UNDP (2006) study are adapted to derive the Hazard Risk score for the survey islands. To enable a scale of 0 to 3, the five risk regions in the hazard risk maps for the three hazards are condensed into four (Figure 7-3a, b, c), by combining hazard regions 2 and 3 as UNDP, 2007 indicated that they have the lowest variation within the five regions.

The definition of storm surge and flooding used in the study UNDP (2006) differs to the definition of flooding that is used in this research. Thus, to derive a similar geographical hazard mapping, the hazard risk mapping in DIRAM study, (UNDP, 2007) is used. Flooding risk increases from Moderate to High going from both East to West and North to South (UNDP, 2007). Hence, a diagonal demarcation from North-West to South-East is assumed to roughly represent the two hazard regions (Moderate and High) for flooding, since all regions have at least moderate risk of flooding (figure 7-3d).

SLR risk was assumed to be the same for all islands in the country and Coastal Erosion risk is taken from Table 7-8. Table 7-9 shows the island level Hazard Risk scores (IHR) for the surveyed islands based on the above methodology.

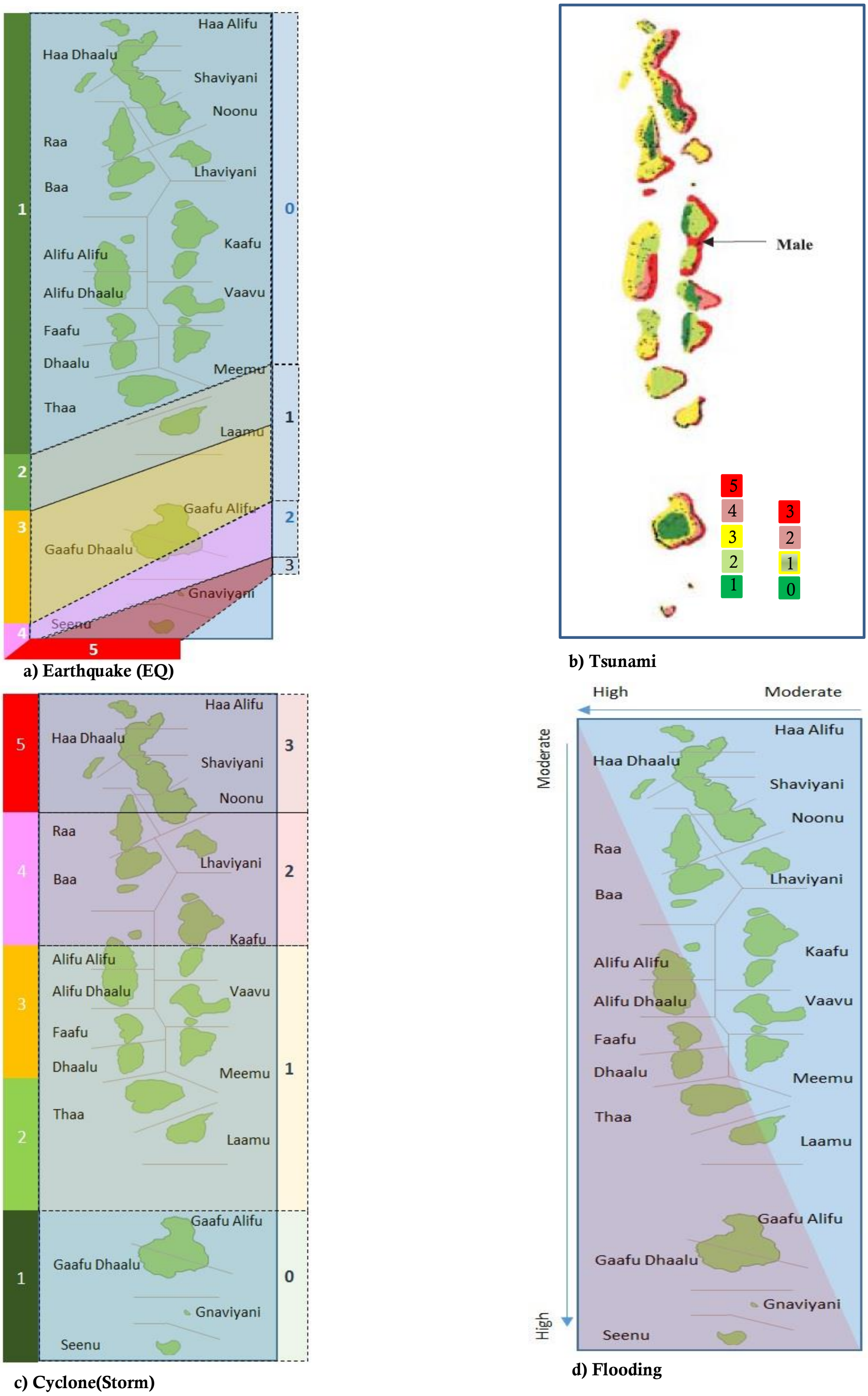


Figure 7-3 Hazard Risk map showing variations in earth quake, tsunami, cyclone, and flood hazard risk across the RoM. Highlights show how the five risk regions (scales on the left) for a) earthquake(EQ), b) tsunami, and c) cyclones (from UNDP (2006) are condensed into three (scales on the right) for the purposes of THOSHI.

Table 7-9 Hazard Risk for surveyed islands (adapted and combined from (UNDP (2007) and (UNDP, 2006))

ISLANDS	Island level Hazard Risk scores (IHR)					
	SLR	Tsunami	EQ	Tropical Cyclones	Flooding/ Swells	Coastal Erosion
HDh. Kulhudhuffushi	3	3	0	3	2	2
Sh. Funadhoo	3	3	0	3	2	2
K. Thulusdhoo	3	3	0	2	2	3
Dh. Kudahuvadhoo	3	2	0	1	3	2
Th. Vilufushi	3	3	0	1	3	2
L. Gamu	3	3	1	1	3	2
Ga. Villingili	3	3	1	0	3	3
GDh. Thinadhoo	3	1	1	0	3	2
S. Feydhoo	3	3	3	0	3	2
S. Hithadhoo	3	1	3	0	3	2

The second step is to identify the resiliency of coastal protection measures to each hazard identified above. The data on mapping resiliency of CP measures in the RoM to hazards selected for use in THOSHI is not available in any one literature. Therefore, the methodology proposed to obtain sensitivity index for wave and water level data in 'ECOPRO project', "make decisions based on less accurate but more readily available information" is adapted (Dollard, 1998). In this regard, the resiliency of different measures to specific hazards was derived from a set of relevant studies and survey data. Five studies were selected, including two from the RoM, which examined the resiliency of coastal protection measures, and the data from the survey of Professionals' Perspectives of coastal protection in the RoM' was used as a sixth study with equal weight given to all.

The studies were selected based on a number of factors; the studies that cover more number of measures similar to the RoM, the similarities in the environmental context to that of the RoM, and the acceptance of such studies to the decision makers in the RoM. The 'Survey of climate change adaptation measures in the Maldives' (MHE, 2011b) and 'Formulation of Risk Resilient Coastal Protection in the Maldives' are studies conducted for the RoM. USACE CEM, Eurosion guide, and Cummings et al. (2012) are guidelines that are followed by engineers in the RoM.

Scores are given based on how many studies rate it resilient over the number of studies that examined the resiliency or effectiveness of the measure against specific hazards. If n number of studies (out of the 6 considered) concluded measure x to be resilient to hazard y, the hazard resiliency score HRE_{xy} is given the score $n/6$ (Table 7-10). Thus, the more studies that conclude a measure to be resilient, the higher the resiliency score would be.

Thus, the Multi-Hazard Resiliency score for measure x, $MHRE_x$ is calculated as:

$$MHRE_x = \frac{\sum_{y=1}^{6}(IHR_y \times HRE_{xy})}{\sum_{y=1}^{6} IHR_y} \qquad \text{Eq. (3)}$$

where x= coastal protection measure, y=hazard, IHR=Island level Hazard Risk, HRE=Hazard Resiliency score.

Table 7-10 Resiliency of measures against hazards as evidenced in selected studies

		Hazard Resiliency scores (HRE)					
Technical Category	**Hazard(y)** / **Measure (x)**	**1. Sea-Level Rise**	**2.Tsunami**	**3. Earthquake**	**4. Tropical Cyclones**	**5. Flooding / Swells**	**6. Coastal Erosion**
Breakwater	Rock Armour	6/6 ABCDEF	4/5 ABCDF	2/3 ABF	4/4 ABEF	5/5 ABDEF	6/6 ABCDEF
	Tetrapods	3/3 ABF	2/3 ABF	2/3 ABF	3/3 ABF	6/6 ABCDEF	6/6 ABCDEF
	Sand Cement Bags	2/3 ABF	1/3 ABF	1/3 ABF	1/3 ABF	2/3 ABF	2/3 ABF
	Geobags	3/3 ABF	2/3 ABF	2/3 ABF	2/3 ABF	2/3 ABF	2/3 ABF
	Caisson	4/4 ABDE	4/4 ABDE	3/4 ABDE	4/4 ABDE	3/4 ABDE	3/4 ABDE
	Steel Sheet piles	6/6 ABCDEF	5/5 ABDEF	3/4 ABDE	3/3 ABF	2/3 ABF	2/3 ABF
Revetments	Sand Cement Bags	2/3 ABF	1/3 ABF	1/3 ABF	1/3 ABF	2/3 ABF	2/3 ABF
	Concrete	2/3 ACD	2/3 ACD	1/3 ACD	2/3 ACD	2/3 ACD	2/3 ACD
	Rock armours	6/6 ABCDEF	4/5 ABCDF	2/3 ABF	4/4 ABEF	5/5 ABDEF	6/6 ABCDEF

Reclamation	Reclamation	4/6 ABCDEF	2/6 ABCDEF	4/6 ABCDEF	2/6 ABCDEF	4/6 ABCDEF	2/6 ABCDEF
Sea walls / bulkheads	Concrete	4/4 ABDE	4/4 ABDE	3/4 ABDE	4/4 ABDE	3/4 ABDE	3/4 ABDE
	Steel Sheet Piles	6/6 ABCDEF	5/5 ABDEF	3/4 ABDE	3/3 ABF	2/3 ABF	2/3 ABF
	Sand Cement Bags	2/3 ABF	1/3 ABF	1/3 ABF	1/3 ABF	2/3 ABF	2/3 ABF
Gabions	Gabions	2/3 ABF	1/3 ABF	1/3 ABF	1/3 ABF	2/3 ABF	3/3 ABF
Groynes	Sand cement bags	2/3 ABF	1/3 ABF	1/3 ABF	1/3 ABF	2/3 ABF	2/3 ABF
	Geo Bags	3/3 ABF	2/3 ABF	2/3 ABF	2/3 ABF	2/3 ABF	2/3 ABF
	Rock Armour	6/6 ABCDEF	4/5 ABCDF	2/3 ABF	4/4 ABEF	5/5 ABDEF	6/6 ABCDEF
Vegetation	Vegetation	1/3 ABDF	3/3 ABD	1/3 ABD	1/3 ABD	2/3 ABD	1/3 ABD
Beach Nourishment	Beach nourishment	4/6 ABCDEF	2/6 ABCDEF	4/6 ABCDEF	2/6 ABCDEF	4/6 ABCDEF	2/6 ABCDEF

Note: the score represents the proportion of studies that identify a given measure to be resilient against the corresponding hazard. The uppercase letters beneath the score represent a reference key for the selected studies that evaluate the performance of that measure against the corresponding hazard.

***Reference Key*:**

A- Professionals' Survey by Author
B- Salman et al. (2004)
C- MHE (2011b)
D- McCue et al. (2012)
E- USACE (1984,1995,2003)
F- Cummings et al. (2012); Swan River Trust (2009)

7.5.3 Socio-aesthetics and environmental acceptability:

The final step in this stage is calculating the score for socio-aesthetics and environmental acceptability. A combination of factors and sub-factors with regard to social, environment and aesthetics of different measures identified through the literature review and research will be evaluated in this step.

Sub-factors were obtained through the literature review, later refined with the survey. Table 7-11 shows the sub-factors selected and individual weights given to each sub-factor.

Table 7-11 Evaluation Factors selected for Socio-aesthetics and Environmental Acceptability, with their individual factor weights

Factor	Sub-Factor (i)	Weight (w)	Reference
Aesthetics	Nature and the attractiveness of material	3	Dupray et al. (2010), Salman et al. (2004), UNDP (2007), (USACE, 1981b)
	Landscape - aesthetics value to amenity	3	McCue et al. (2012), (USACE, 1981b)
Social	Not a navigation hazard	3	McCue et al. (2012), Salman et al. (2004),
	Not Hazardous to people walking on them	2	USACE (1984,1995,2003), (USACE, 1981b)
	Does not limit view from upland areas	2	Salman et al. (2004), UNDP (2007) , (USACE, 1981b)
	Provide sheltered mooring areas	2	Cummings et al. (2012); Swan River Trust (2009) Salman et al. (2004), UNDP (2007), (USACE, 1981b)
	Does not affect use of beach	2	USACE (1984,1995,2003), Salman et al. (2004), UNDP (2007), (USACE, 1981b)
	Provide more beach for shoreline recreation	2	McCue et al. (2012), (USACE, 1981b)
Environmental	Provide improved/additional marine/wild life habitats	1	Cummings et al. (2012); Swan River Trust (2009) Salman et al. (2004), UNDP (2007) , (USACE, 1981b)
	Does not increase turbidity	2	McCue et al. (2012), (USACE, 1981b)

Similar methodology used to calculate Technical Viability has been used to obtain the Socio-Aesthetic and Environmental Acceptability scores for each measure (Table 7-12).

A score is allocated to each measure with regards to the weighting sub-factor on a discrete scale of 0 to 3, where 0=very poor, 1=poor, 2=fair and 3=good. Thus, the maximum possible score for any factor will be 3 and the proportional score(s) will be the raw score divided by the maximum possible score. The weighted score(S) for the individual factor i is then obtained by multiplying the proportional score s by weight w.

$$S_i = s_i \times w_i \; ; \qquad \text{Eq. (4)}$$

$$where\ i = \{1 \ldots .10\}, corresponding\ to\ each\ subfactor$$

Thus, the Socio-Aesthetic and Environmental Acceptability score (SE) for measure x is obtained by the sum of the weighted scores divided by the sum of weights.

$$SE_x = \frac{\sum S_i}{\sum w_i} \;\; ; \;\; i = \text{Error! Bookmark not defined.} \qquad \text{Eq. (5)}$$

Table 7-12 Socio-aesthetics and Environmental Acceptability score for different coastal protection measures

		Scores for sub factors											
Technical Category	**Sub-Factors (i)** *weights* / **Measure (x)**	**(1)** *3*	**(2)** *3*	**(3)** *3*	**(4)** *2*	**(5)** *2*	**(6)** *2*	**(7)** *2*	**(8)** *2*	**(9)** *1*	**(10)** *2*	**Socio-aesthetics Score (SE)**	**SE weighted at 15%**
Breakwater	Rock Armour	2	2	1	1	2	3	3	2	3	3	0.70	10.45
	Tetrapods	2	2	1	1	2	3	3	2	2	2	0.65	9.77
	Sand Cement Bags	1	1	1	2	3	2	1	1	1	2	0.48	7.27
	Geobags	2	2	2	2	2	2	2	1	2	1	0.61	9.09
	Caisson	3	3	2	3	2	3	1	1	2	1	0.73	10.91
	Steel Sheet piles	2	3	2	2	2	3	1	1	2	1	0.65	9.77
Revetments	Sand Cement Bags	1	1	2	2	3	2	1	2	1	2	0.56	8.41
	Concrete	2	2	2	2	3	2	1	2	2	2	0.67	10.00
	Rock armours	1	1	2	1	2	2	2	1	2	1	0.48	7.27
Reclamation	Reclamation	3	3	3	3	3	1	3	3	2	2	0.89	13.41
Sea walls	Concrete	2	2	2	3	2	3	1	1	2	1	0.64	9.55
	Steel Sheet Piles	2	2	2	2	2	3	1	1	1	1	0.59	8.86
	Sand Cement Bags	1	1	2	2	2	2	2	1	1	1	0.50	7.50

Gabions	Gabions	1	1	1	1	3	2	2	2	3	3	0.58	8.64
Groynes	Sand cement bags	1	1	1	2	2	2	2	3	2	2	0.56	8.41
	Geo Bags	2	2	1	2	2	2	2	3	1	1	0.61	9.09
	Rock Armour	1	1	2	1	2	2	2	1	2	1	0.48	7.27
Vegetation	Vegetation	2	2	1	1	1	1	2	2	1	1	0.48	7.27
Nourishment	Nourishment	3	3	3	3	3	1	3	3	2	2	0.89	13.41

Once all three parameter values and the total score of Technical Evaluation for each feasible measure is calculated, the feasible measures can be ranked according to their total scores. Table 7-13 shows the total Technical Evaluation scores of all the measures selected for THOSHI using MHRE values of Kulhudhuffushi in Table 7-9.

Table 7-13 Total weighted technical evaluation scores for the measures selected for THOSHI using MHRE values of Kulhudhuffushi

		Weighted Technical Parameter Scores			**Total Technical Score**
Technical Category	**Measure**	**Technical Viability (TV)**	**Multi-Hazard Resiliency (MHRE)***	**Socio-aesthetic & environmental acceptability (SE)**	
Breakwater	Rock Armour	64.44	14.31	10.45	**89.2**
	Tetrapods	62.22	13.85	9.77	**85.84**
	Sand Cement Bags	44.44	7.69	7.27	**59.4**
	Geobags	48.89	11.15	9.09	**69.13**
	Caisson	52.22	13.85	10.91	**76.98**
	Steel Sheet piles	58.89	13.46	9.77	**82.12**
Revetments	Sand Cement Bags	44.44	7.69	8.41	**60.54**
	Concrete	54.44	10.00	10.00	**74.44**
	Rock armours	54.44	14.31	7.27	**76.02**
Reclamation	Reclamation	28.89	6.92	13.41	**49.22**
Sea walls	Concrete	62.22	13.85	9.55	**85.62**
	Steel Sheet Piles	54.44	13.46	8.86	**76.76**

	Sand Cement Bags	44.44	7.69	7.50	**59.63**
Gabions	Gabions	42.22	8.46	8.64	**59.32**
Groynes	Sand cement bags	44.44	7.69	8.41	**60.54**
	Geo Bags	48.89	11.15	9.09	**69.13**
	Rock Armour	56.67	14.31	7.27	**78.25**
Vegetation	Vegetation	46.67	8.08	7.27	**62.02**
Nourishment	Nourishment	28.89	6.92	13.41	**49.22**

**MHRE values of Kulhudhuffushi*

7.6 STAGE 5 FINANCIAL EVALUATION OF FEASIBLE MEASURES

Financial evaluation of the measures is particularly important for countries like the RoM where resource scarcity and availability of project funding play a major role in the selection of coastal protection measures. Financial costs are structure specific, and evaluation based on capital cost alone may not be a true indicator of the financial feasibility of a measure. Hence, total cost, which is the sum of capital cost and maintenance cost, over the estimated life-time of the structure is calculated. However, since the estimated life-time of the structures differ considerably; the average cost per meter, per year is taken as a basis for ranking and comparison.

Durability, frequency of maintenance and the percentage of maintenance required per period for different measures are vital in deciding the true cost of a measure. Some measures may have very high capital cost but may last for over 50 years while an alternative low capital cost measure may last only for a year or two. The cost of construction (maintenance, labour and plant) will be subjected to location and proximity of the project site from the capital city, Male', as resources are mobilised mostly from Male' to the project island when the need arises. For the purpose of THOSHI, location factor weight is not taken separately for several reasons. Firstly, evaluation is between different measures but for the same island, and so most of the measures would carry the same location advantage or disadvantage. Secondly, the financial data from which the financial evaluation scores are derived, do not exhibit this location bias in their costs. Most of the differences in those costs seem to be absorbed into preliminary mobilisation costs. Finally, even if there were difference in costs due to location, obtaining this level of accuracy would go beyond the scope of this research. Hence, location factor weight is assumed to be negligible for the evaluations.

The financial evaluation was derived by using a set of relevant studies and data obtained from the RoM. Survey of Climate Change Adaptation measures in the RoM has been used as the primary reference. Data obtained from other contractors have been used to cross check the values. It is important to note that there is a significant cost variation in the same measure across different companies. Resource availability, sourcing methods, types of material used, placement and construction methods, and the project financing play a key role in the cost.

To derive the total cost for a measure x (TC_x), the first step is to identify the initial cost or capital cost per linear meter (I_x). The frequency of maintenance ($Fmain_x$) and the proportion of maintenance cost (as a proportion of the Initial cost I_x) per period ($Pmain_x$) is then calculated. It is important to note that these aspects also vary from place to place. $Fmain_x$ and $Pmain_x$ for THOSHI are calculated based on the information obtained from MHE (2011b) and the coastal contractors in the RoM. Finally, average cost per meter per year (ATC_x) is calculated as:

$$ATC_x = \frac{TC_x}{Dlife_x} = \frac{I_x + (I_x \times Fmain_x \times Pmain_x)}{Dlife_x} \qquad \text{Eq. (6)}$$

Where; Dlife is the design life for the measure x

While decision makers can adjust the total cost with the most recent market rates, for the purposes of the case studies in this research, average cost per meter per year calculated in Table 7-14 is used. This table 7-14 shows the derivation of average cost per meter per year for each coastal protection measure – calculated from the data obtained from coastal protection contractors in the RoM and MHE (2011b).

Once the scores for both technical and financial evaluations are calculated, to combine the results for Financial and Technical evaluation and enable a final ranking of the measures for decision making, a Financial/Technical ratio is derived by dividing the Financial cost by the Technical score. For measures with lower Financial cost or higher Technical scores, the ratio is lower and vice versa. Thus, measures that have the lowest Financial/Technical ratio are most feasible and ranked first. The lower the financial to technical score ratio the more feasible the measures would be. If required, the decision makers can select as many as they prefer for cost-benefit analysis.

It is in the discretion of policy makers whether they use all the ranked measures or whether they impose a criterion of minimum technical score for qualifying into financial evaluation. However, an important caveat is that due to the immense dispersion of the cost of protection measures, even if a measure scores very low in the technical evaluation, it could still manage to outrank other more technically effective measures solely due to its low cost.

Table 7-14 Derivation of total cost for each coastal protection measure

Technical Category	Measure	Capital Expenditure(I)/lm (MVR)	Interval of maintenance (yrs)	Frequency of Maintenance within design life (*Fmain*)	Proportion of maintenance / period (*Pmain*)	Design Life (*Dlife*) (yrs)	Total Cost (TC)/lm (MVR)	Average Total Cost /lm/year (MVR)
Breakwater	Rock Armour	37000	10	5	0.05	50	46250	925
	Tetrapods	71859	20	2.5	0.05	50	80841	1617
	Sand Cement Bags	11925	1	10	0.20	10	35775	3578
	Geobags	23953	5	3	0.20	15	38325	2555
	Caisson	36000	15	2.9	0.05	44	41280	938
	Steel Sheet piles	40000	20	2.4	0.05	48	44800	933
Revetments	Sand Cement Bags	9585	2	5	0.10	10	14378	1438
	Concrete	20360	8	3.1	0.05	25	23541	942
	Rock armours	37000	10	5	0.05	50	46250	925
Reclamation	Reclamation	450	2	2.5	0.30	5	788	158
Sea walls	Concrete	36000	20	2.5	0.05	50	40500	810
	Steel Sheet Piles	40000	20	2.5	0.05	50	45000	900
	Sand Cement Bags	11925	2	5	0.10	10	17888	1789
Gabions	Stone/Rock filled nets	9500	2	5	0.20	10	19000	1900
Groynes	Sand cement bags	11925	3	3.3	0.10	10	15900	1590
	Geo Bags	23953	3	5	0.10	15	35930	2395
	Rock armours	37000	10	5	0.05	50	46250	925
Vegetation	Planting	900	30	1.7	0.05	50	975	20
Beach Nourishment	Beach nourishment	1000	2	2.5	0.50	5	2250	450

7.7 STAGE 6 CONDUCT COST-BENEFIT ANALYSIS ON SHORTLISTED MEASURES

The Cost-benefit analysis (CBA) is an optional component of THOSHI and can be undertaken to determine further viability and socioeconomic impacts of having or not having a measure. A cost –benefit analysis could be undertaken to determine the socioeconomic viability of proposed adaptation measures. It differs from a straightforward financial evaluation in that it considers all gains (benefits) and losses (costs) regardless of who will be impacted to what level. In practical terms, many benefits or damages are not readily estimable in monetary terms (e.g. the losses that a community will incur in such a disaster if there was no protection or not sufficient protection in place) (Dupray et al., 2010; McCue et al., 2012).

Important factors to consider in a CBA are natural and built environment, social (impacts on local population and employment (Beca, 2010), and other economic costs. Some of the measures can be eliminated according to the results of the CBA.

7.8 Stage 7 Stakeholder Validation and Selection of Appropriate Measures

The final stage in THOSHI is the validation of the measures by stakeholders. In this stage, the measures with the lowest financial versus technical evaluation are presented to stakeholders for validation. In cases where CBA is conducted, the shortlisted best measure(s) from the CBA will be presented to the stakeholders for validation. As there are no clear-cut solutions for coastal erosion issues, the stakeholders and decision makers can decide on any of the measures that the technical evaluation or the CBA finds feasible. Priority will be given to the measures that rank highest (i.e. lowest financial vs technical score). Once the best measure(s) are selected, design and construction guidelines can be followed for implementation of different measures (Beca, 2010; McCue et al., 2012).

7.9 Chapter Summary

The comprehensive survey exercises with the general public and professionals, alongside the literature review facilitated the development of a decision support framework especially for RoM context, called THOSHI, which is presented in this chapter. The chapter discussed the concept of THOSHI, and described the detailed stage by stage evaluation process proposed. The outcome of the evaluation allows decision makers to compare technical parameters such as technical viability, hazard resiliency and socio-aesthetic and environmental acceptability of the measures. It also allows the decision makers to compare financial parameters such as capital cost, repair and maintenance costs to identify the cost-effectiveness of different measures. It is reinforced by local stakeholder inputs and decision makers still have the option to adopt or reject the final outcome. The next chapter presents case studies of the application of THOSHI to two major islands' coastal protection problems.

8 THOSHI CASE STUDY APPLICATIONS

8.1 INTRODUCTION

This chapter presents the results of implementing the coastal protection DSF, THOSHI, using two case studies conducted on Haa Dhaalu Kulhudhuffushi and Gaafu Dhaalu Thinadhoo (Figure 8-1). These islands are considered two of the most urbanized islands in the RoM, being the economic, medical, educational, and development hubs in their respective regions and are included in the ten islands selected for population and development consolidation under DIRAM study. Additionally, these two islands have implemented most of the coastal protection measures available in the RoM. Table 8-1 presents the criteria used to select islands for the case study.

Table 8-1 Selection criteria for case study islands (adapted from Salman et al. (2004))

Criteria	Objectives	Case study 1- Kulhudhuffushi	Case Study 2 - Thinadhoo
Coastal protection problem	Representation of coastal protection issue(s) that justifies the need for action	Severe beach erosion mostly in the north-eastern side. Wave over topping, and flooding reported.	Severe beach erosion and flooding in the south, south west, and north-east coastline.
Physical types	Representative of the physical types of coasts in the country, including (i) shingle coasts, (ii) sandy beaches, and (iii) wetlands	Mostly shingle to sandy beaches around the island with few hard substrata covered areas. South eastern coastline is shingle to rocky with an average height of 1.75m in the coastal ridge. Beach rocks can be seen in some parts in the coastline. The East coastline is shingle to rubble with over 3m in the coastal ridge. Beach rocks can be seen in some parts of the coastline. North east coastline is mostly shingle to rubble with an average height of 1.5m from MSL. Rubble can be seen in the lagoon. Northern most coastline is shingle to sandy beach with an average 1.75m height from MSL. Rock and rubble can be seen in the shallow sea bed. North east coastline is shingle to sandy beach with average height of 1m. This part of the lagoon is covered in sea grass.	Mostly shingle to sandy beaches around the island with few hard substrata covered areas. South eastern coastline is very low lying (0.5m-0.75m) with scarp erosion. Beach material is shingle to sandy. Sea grass in the shallow area can be seen towards the south end. South west to southernmost tip is mostly shingle to rocky beach. Scarp erosion is visible. Rocky substrate towards reef edge. From North west towards northernmost end is shingle to sandy beach. Average height of berm is 1.5m. Shallow region is covered in sea grass. Northern coastline towards the northern most end is shingle to sandy beach reclaimed to an average height of 1.25m. Scarp erosion is visible. 50m from the coastline the lagoon leads to deeper region.

		South west coastline is now reclaimed to a height of 1.75m, and the material is mostly white sand. Wetlands on south and north end of the island.	Wetlands on the Southern end has been reclaimed. Small wetland area in *Maafushi* island (north of Thinadhoo) joined with Thinadhoo by reclamation.
Policy options	Applicability of the 5 generic policy options: (i) hold the line, (ii) move seaward, (iii) managed realignment, (iv) limited intervention, (v) do nothing.	Possible to implement all policy options that are applicable to the RoM coastlines.	Possible to implement all policy options that are applicable to the RoM coastlines.
Social and economic functions	Representative of the major socio-economic functions: (i) industry, transport and energy, (ii) tourism and recreation, (iii) urbanization, (iv) fisheries, (v) nature.	Socio-economic functions in the island include northern port facilities, guesthouses, and fisheries activities. Kulhudhuffushi is highly urbanized and is one of the largest inhabited islands of the RoM with a surface area almost equivalent to Male'.	Socio-economic functions in the island include guesthouse tourism, faculties of the Maldives National University, and fisheries activities. Thinadhoo is the most populous island in the largest atoll in the RoM.
Governance	Highlight respective responsibilities of the different level of administration, namely: (i) the national level, (ii) the regional level, and (iii) the local level.	Three tiers of administration including government offices, atoll (regional) council and local island council in the island	Three tiers of administration including government offices, atoll (regional) council and local island council in the island
Willingness to participate	Willingness of local stakeholders to provide information is a key criterion for selecting sites	Local councils and the public participated in the surveys and interviews willingly and shared their views during a discussion with key stakeholder.	Local councils and the public participated in the surveys and interviews willingly and shared their views during a discussion with key stakeholder.
Technical Solutions	Representative of existing coastline protection practices including innovative technical solutions	Most of the coastal protection measures are seen along on the highly modified coastline	Apart from breakwaters, most of the other types of coastal protection measures can be seen along the coastline
Geographical distribution	Well balanced geographic distribution of the islands, representing geographic variations of both north and south of the RoM	Located 6°37'N and 73°04'E on the eastern rim of Haa Dhaalu Atoll (HDh), 276 kms North of Male'	Located 00°31'49"N and 73°59'50"E on the western rim of Gaafu Dhaalu Atoll (GDh), 409.2 km South west of Male'

The geographic and environmental context of the case study islands are described in this chapter followed by the implementation of the proposed DSF, THOSHI on coastal protection problems. Finally, the chapter discusses the types of measures recommended by THOSHI and practical solutions that are already being implemented.

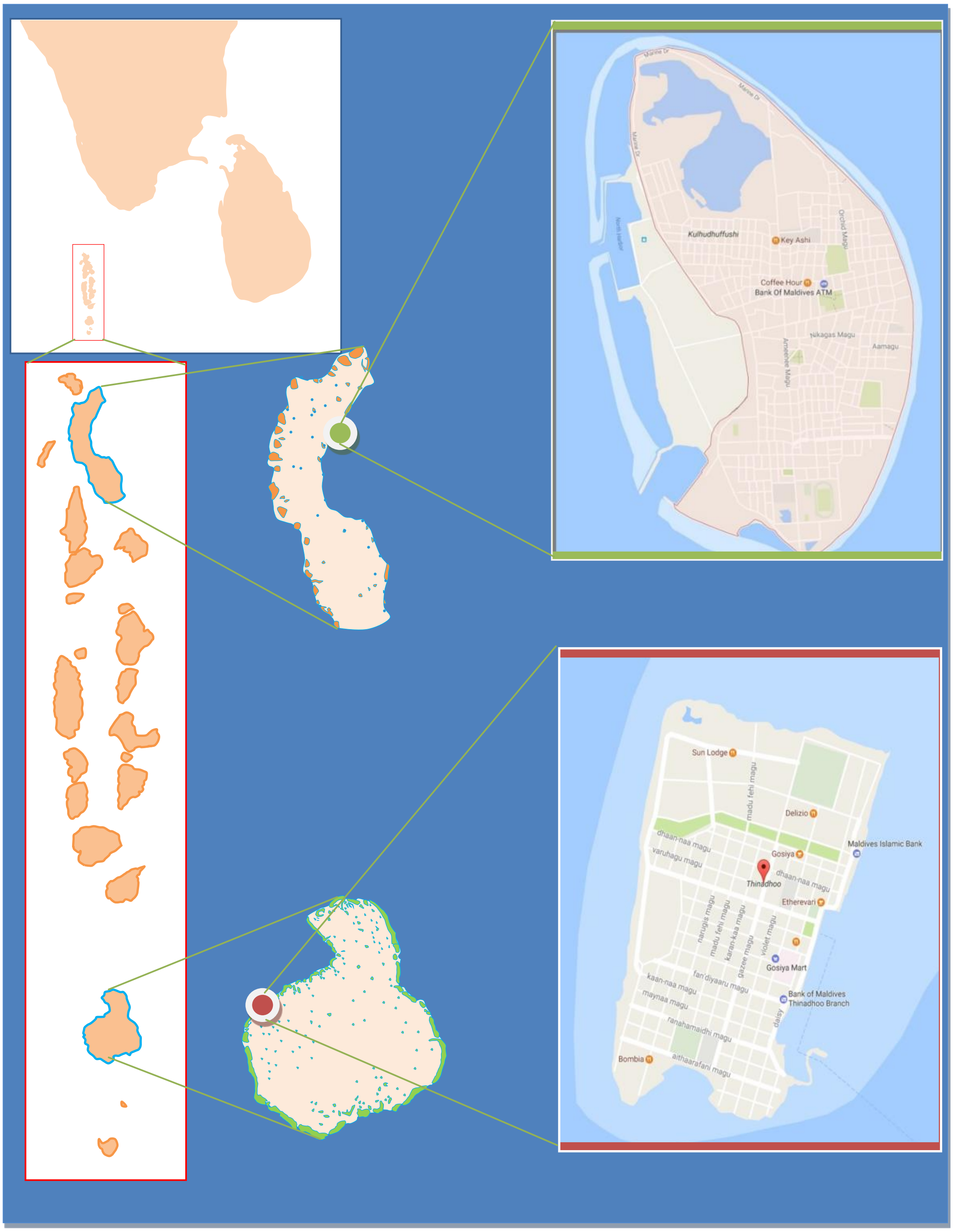


Figure 8-1 Location of the RoM, and case study islands Kulhudhuffushi and Thinadhoo

8.2 CASE STUDY 1 – HDH. KULHUDHUFFUSHI

8.2.1 Geographic and environmental setting

Kulhudhuffushi is the administrative capital of Haa Dhaalu atoll (HDh) and is highly urbanized. It is the 11th largest island in the RoM and has a population of 8,440 (NBS, 2014). Approximately 20 percent of the households are located near the coast (MEE, 2013b).

The kidney shaped island, oriented northwest-southeast direction has an average length and width of 2530m and 900m respectively. Kulhudhuffushi has a shallow reef flat of length 2870m and width 1780m. The island has a 6.51km long coastline around the island, heavily modified since the construction of the island inner harbour and the regional port. The island originally had two wetland areas of total 33.46ha on the northern and southern end of the island. The northern wetland area has been reclaimed to provide additional land for housing. A total of 43ha of land have been reclaimed from port, old harbour and west central zone (MEE, 2013b).

Kulhudhuffushi is subject to multi-hazards threatening the coastal stability of the island. Table 8-2 shows a summary of multi-hazard incidents recorded for Kulhudhuffushi.

Table 8-2 Summary of multi-hazard incidents recorded for Kulhudhuffushi

Hazard category	Hazards identified for this study	Incidents
Geological	Earthquakes	There was no record of an earthquake in the RoM. However, stakeholders confirmed that tremors were felt from distant earth quakes in the past. The nearest source of earthquake activity is the Carlsberg ridge located southwest of the country (UNDP, 2006).
	Coastal Erosion	Aerial images from 1969 and 1996 show an area of approximately 300m long and 150 wide from north eastern coastline has been modified due to erosion. Also, erosion is observed at the southern side of the newly reclaimed land.
Meteorological	Tropical Cyclones	11 cyclones crossed the RoM in the last 128years (UNDP, 2006). Kulhudhuffushi is in the area where the impact is highest felt. UNDP (2006) also confirms the probability of occurrence for 65knots and above is high in Kulhudhuffushi.
Hydrologic	Tsunamis	No major damages have been reported from Kulhudhuffushi in the only tsunami recorded in the RoM in December 2004. Kulhudhuffushi is still at considerable risk from tsunami hazards due to its close proximity to eastern rim of the atoll.
	Coastal Flooding (Storm surges and Swell waves)	Swells predominantly approach the RoM from southerly direction throughout the year (Young, 1999). Located in a moderate storm surge zone, Kulhudhuffushi is also exposed to storm surges generated due to tropical cyclones. Coastline of Kulhudhuffushi is exposed to wind generated waves governed by monsoonal winds. West and East coasts are mostly impacted by

		wind generated waves in southwest and northeast monsoon respectively. 18-20 June 2007 *udha* events destroyed parts of the old quay wall at the western side and flooded dwellings within 40m of the coastline. The intensity of swell impacts would be highest in the southern, northern and eastern shoreline. The high ridge in the central part of the eastern shoreline acts as a natural protection. Therefore, wave overtopping is relatively less in this area compared to the south and north end of the island. The western side of the island was susceptible to flooding due to heavy southwest monsoon storm events before reclamation. Probability of storm surge occurrences is low.
Climate Change	Sea Level Rise	Climate change induced SLR would have a devastating impact on most of the islands in the RoM including Kulhudhuffushi. The consequences of SLR would be high for the low lying coastal areas that are prone to hazards such as flooding and tsunamis. Probability of SLR is moderate.

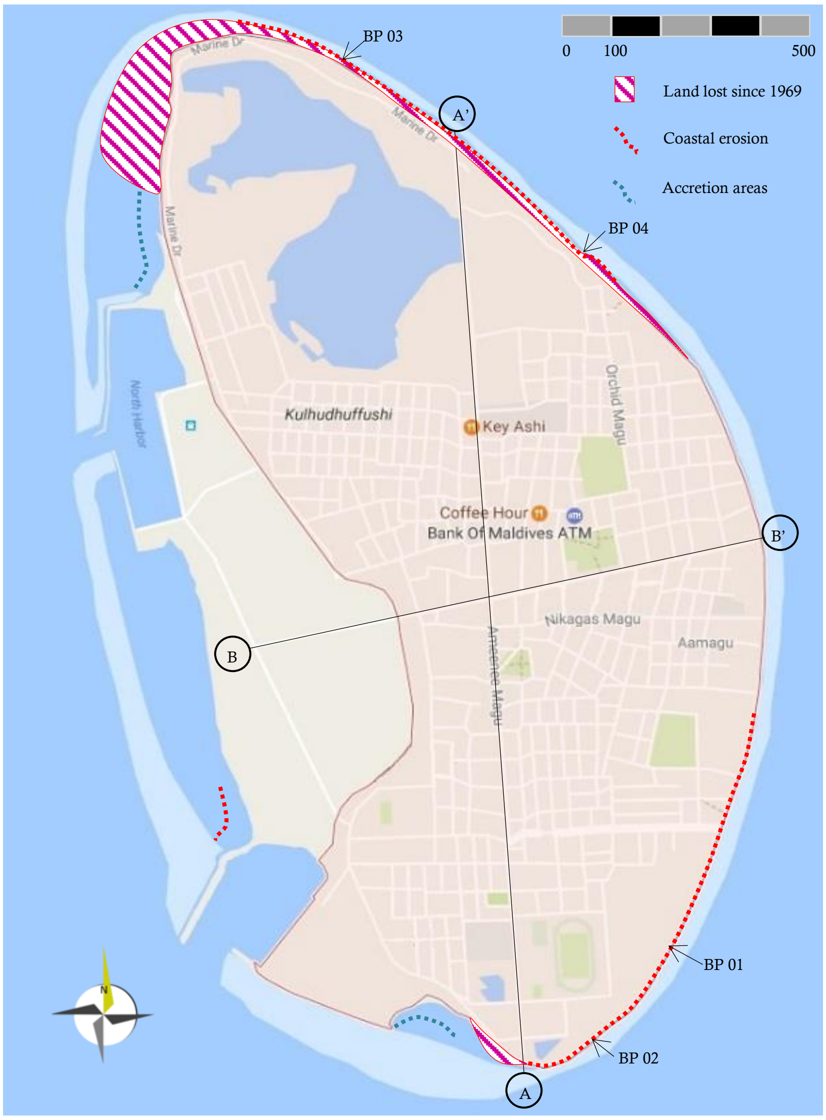


Figure 8-2 Erosion and accretion areas, points with severe beach erosion (BP 01-04) and cross sectional lines (A-A', B-B') of Kulhudhuffushi (adapted from MEE (2013b))

Topographic assessment of Kulhudhuffushi in Figures 8-3, 8-4 and 8-5 (adapted from MEE (2013b)) shows cross sectional view of the island, and beach profiles from areas experiencing erosion. The reclaimed areas and the central area of the island are significantly elevated compared to the rest.

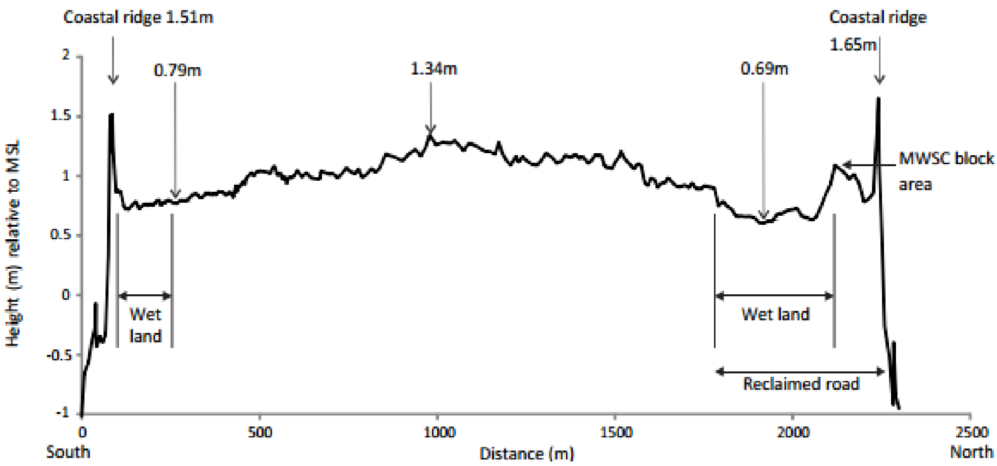


Figure 8-3 Cross sectional view of the island A-A'

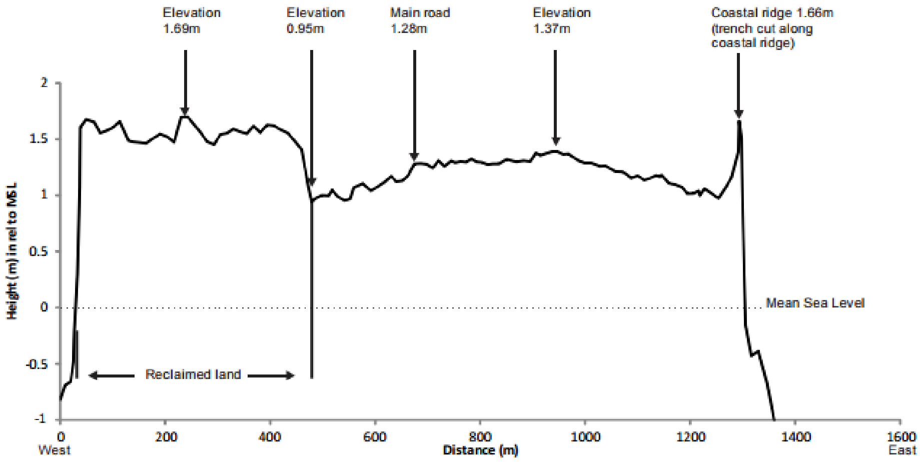
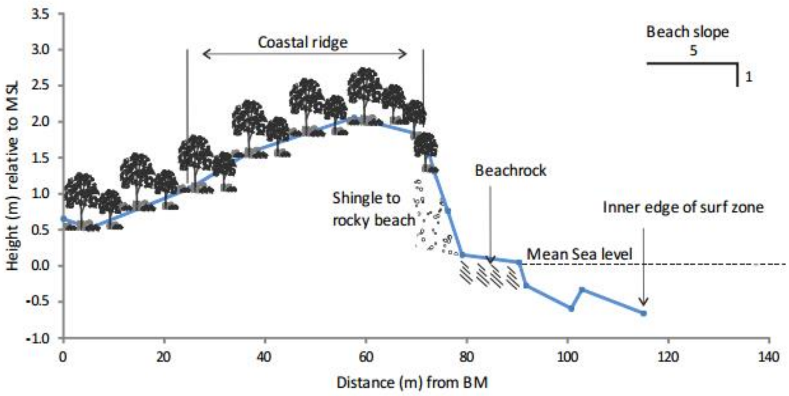
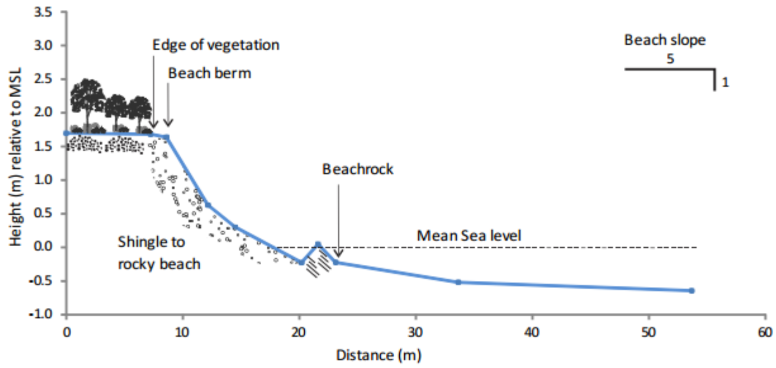


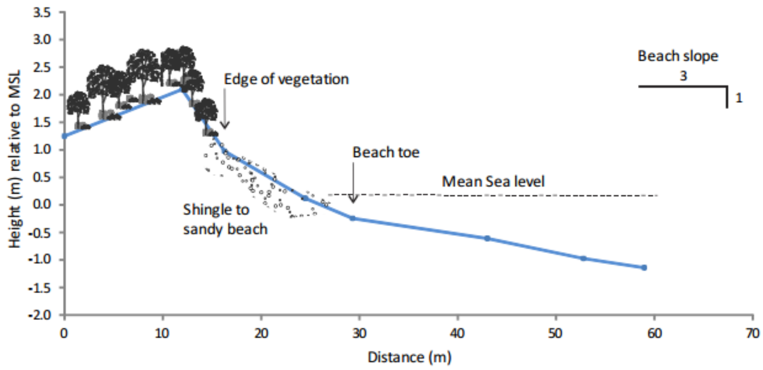
Figure 8-4 Cross sectional view of the island B-B'



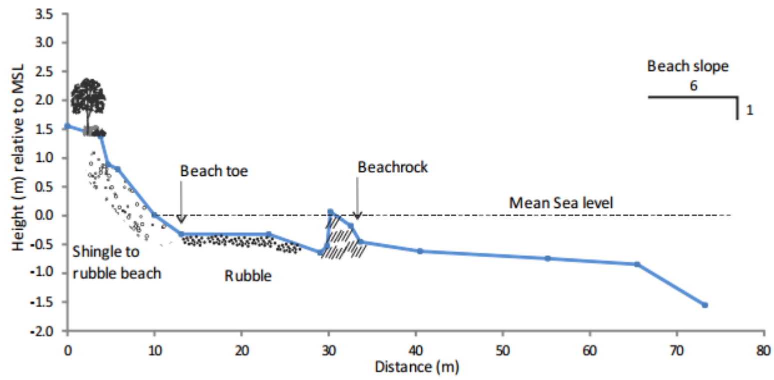
Cross section at point BP01



Cross section at point BP02



Cross section at point BP03



Cross section at point BP04

Figure 8-5 Cross sectional views of the beach profiles at selected points of severe erosion in Kulhudhuffushi

8.2.2 Application of THOSHI for Kulhudhuffushi

STAGE 1: Define coastal protection problem

The coastline of Kulhudhuffushi has been modified considerably over the years due to natural and manmade causes. Aerial images from 1969 and 1996 show approximately 300m length and 150m width of an area has been eroded on the north-eastern corner of the island (Figure 8-2). The modifications on the western coastline are mostly due to development activities. The new harbour in the northwest and the regional port facility in the southwest of the island are protected with rock armour breakwaters on the foreshore. Steel sheet piles and concrete have been used in the port quay wall and harbour seawall respectively. All the coastal protection measures currently installed are reported as functioning well. The residential housing and business establishments on the western coastline have experienced occasional flooding in the past. However, with the reclamation works carried out, they are now located further away from the coastline, reducing the risk of flooding and wave over-topping.

The atoll has a relatively high number of openings on the eastern rim where Kulhudhuffushi is located, and the low number of lagoon reef systems together with the high water depth within the atoll result in the generation of high waves during *Hulhangu* rainy season. Larger sections of the south eastern and north-eastern coastline are susceptible to severe erosion and inundation as they are exposed to waves generated from the East Indian Ocean. According to the stakeholders, the coastal ridge of height 2m and the 70m wide vegetation belt are the only protections keeping this coastal ridge from being undermined (MEE, 2013b).

By examining the severity and regularity of erosion and the existing coastal protection measures and their functionality, the following coastal protection problems are identified for Kulhudhuffushi.

Problem Definition 1: Eastern coastal ridge is failing: If unprotected and the current erosion continues, it has the potential to fully undermine the coastal ridge (BP01, BP02, and BP04). Therefore, a coastal protection measure that will restore and maintain the ridge needs to be implemented.

Problem Definition 2: Severe erosion of the northern coastline (BP03): The Northern coastline around the wetland is experiencing severe coastal erosion and increased flooding due to the wetlands close proximity to coastline (A’). If unprotected, the narrow land strips between the wetland and the coastline would be completely undermined. There are no measures currently implemented in this area.

STAGE 2: Determine Policy Options and Identify Desired Action(s)

Once the problem is identified and detailed, appropriate policies and actions to address the problem can then be selected. Policies can be selected from the five management options and the actions then chosen from the resulting choices under each selected policy as shown in Figure 8-6

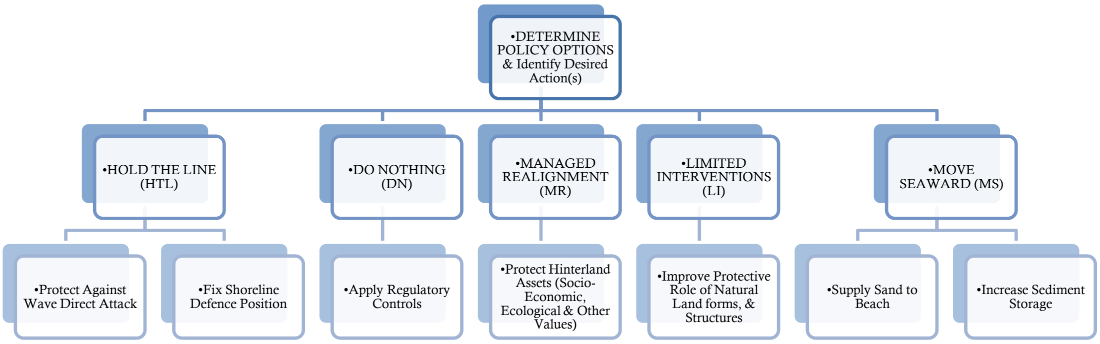


Figure 8-6 Five management policy options and actions available at Stage 2

The facts of the problem identified in stage 1, such as severity of the problem and the geography of the site, will feed the decision on what policy and subsequent action is chosen. An analysis of various policies and the rationale for selecting specific policies for coastal protection is summarized in Table 8-3.

Table 8-3 Policies and actions selected for Kulhudhuffushi in Stage 2 and their rationale

Problem Definition	Policy		Action	Rationale for selecting policy
	Selected	**Rejected**	**Preferred**	
1- Eastern coastal ridge is failing	**HL**		Fix coastline defence position	If the current erosion trend continues it would undermine the coastal ridge. Therefore, a coastal protection measure that will restore and maintain the ridge needs to be implemented. To ease the wave action on the structures that hold coastline position, actions to weaken the wave attacks must be looked into if the cost is not too high.
			Protect against wave direct attack	
		DN		Issue is too severe for doing nothing.
		MR		No space inland for the coastal facilities and population to move inward.

		LI		Problem too severe for limited intervention
		MS		Narrow reef flat - not enough area to move seaward as the problem region is too close to reef edge.
2- Severe erosion on northern coastline	**HL**		Protect against wave direct attack Fix coastline defence position	Northern coastline around wetland is experiencing severe coastal erosion and increased flooding due to wetlands close proximity to coastline. If unprotected, the narrow land strips between the wetland and the coastline would be completely undermined. 'Protect against wave direct attack' is the action desired, thus, 'fix coastline defence position' would also be looked into if the cost is not too high.
		DN		Issue is too severe for doing nothing
		MR		No space inland for the coastal facilities and population to move inward
		LI		Problem too severe for limited intervention
		MS		Narrow reef flat - not enough area to move seaward as the problem region is too close to reef edge

For the reasons identified above, HL was the policy selected for both problems. 'Fix coastline defence position' and 'protect wave direct attack' were the preferred actions for problem 1 and 2 respectively. Therefore, a single set of data was used to evaluate measures for both the problem definitions.

STAGE 3: Select Probable Measures

The policies and actions selected leading to the types of measures, and the pathways to probable measures are shown in the Table 8-4. This gives the decision makers a range of different measures to choose from and a clear justification of the selection.

Table 8-4 Pathways to identify probable measures for the policies and actions selected in Stage 2 for Kulhudhuffushi

Problem	Policy	Action	Type of measure			
			Hard Structural Options (HSO)	**Soft Structural Options (SSO)**	**Non-Structural Options (NSO)**	**Novel and Combined Options (NCO)**
1 & 2	**HL**	Protect against wave direct attack	Offshore BW, Gabions	NA SSO's may not withstand wave attacks hence are not applicable.	NA NSO's are not recommended in areas where the coastline is subjected to wave attack	Offshore Breakwater + Gabions
		Fix coastline defence position	Seawalls, Revetments	NA SSO's are generally not capable of fixing the coastline position.	NA Fixing coastline in position requires structural means hence NSO's cannot be applied.	Seawall + Revetment

As identified in the problem definition stage, there are currently no measures implemented in the problem areas so it was decided to evaluate all the probable measures.

STAGE 4: Technical Evaluation of Feasible Measures

Using the respective formulae for technical viability (TV), multi-hazard resiliency (MHRE), and socio-aesthetics and environmental acceptability (SE) in Chapter 7, the scores for each measure are calculated and ranked in Table 8-5. Figure 8-7 and Figure 8-8 depicts these results for the action 'protect against wave direct attack' and 'fix coastline defence position' respectively.

Table 8-5 Technical evaluation scores and ranking of probable measures for Kulhudhuffushi

POLICY	SELECTED			SCORE				RANK
HL	**Action**	**Technical Category**	**Measure (x)**	**TV (70)**	**MHRE (15)**	**SE (15)**	**Total (100)**	
	Protect against wave direct attack	Breakwater	Rock Armour	64.4	14.3	10.5	89.2	1
			Tetrapod	62.2	13.9	9.8	85.9	2
			Sand Cement Bags	44.4	7.7	7.3	59.4	6
			Geobags	48.9	11.2	9.1	69.2	5
			Caisson	52.2	13.9	10.9	77.0	4
			Steel Sheet piles	58.9	13.5	9.8	82.2	3
		Gabions	Gabions	42.2	8.5	8.6	59.3	7
	Fix coastline defence position	Revetments	Sand Cement Bags	44.4	7.7	8.4	60.5	5
			Concrete	54.4	10.0	10.0	74.4	4
			Rock Armour	54.4	14.3	7.3	76.0	3
		Sea walls / bulkheads	Concrete	62.2	13.9	9.6	85.7	1
			Steel Sheet Piles	54.4	13.5	8.9	76.8	2
			Sand Cement Bags	44.4	7.7	7.5	59.6	6

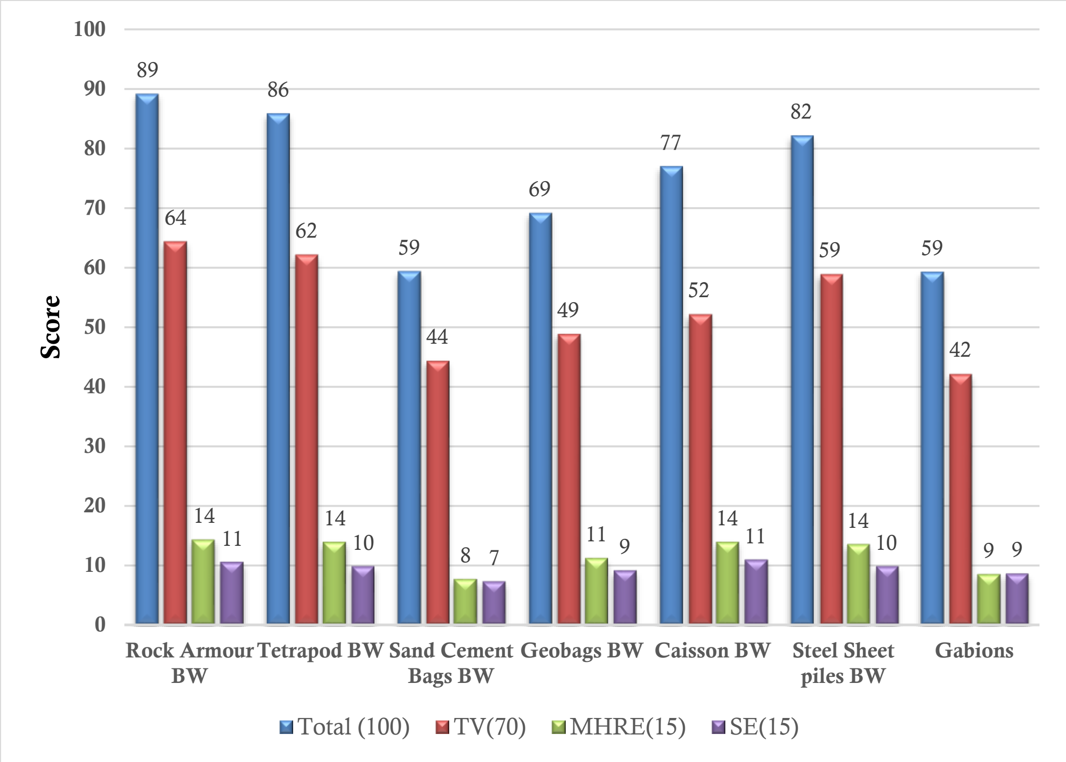


Figure 8-7 Technical evaluation scores of measures under the action 'protect against wave direct attack' in Kulhudhuffushi

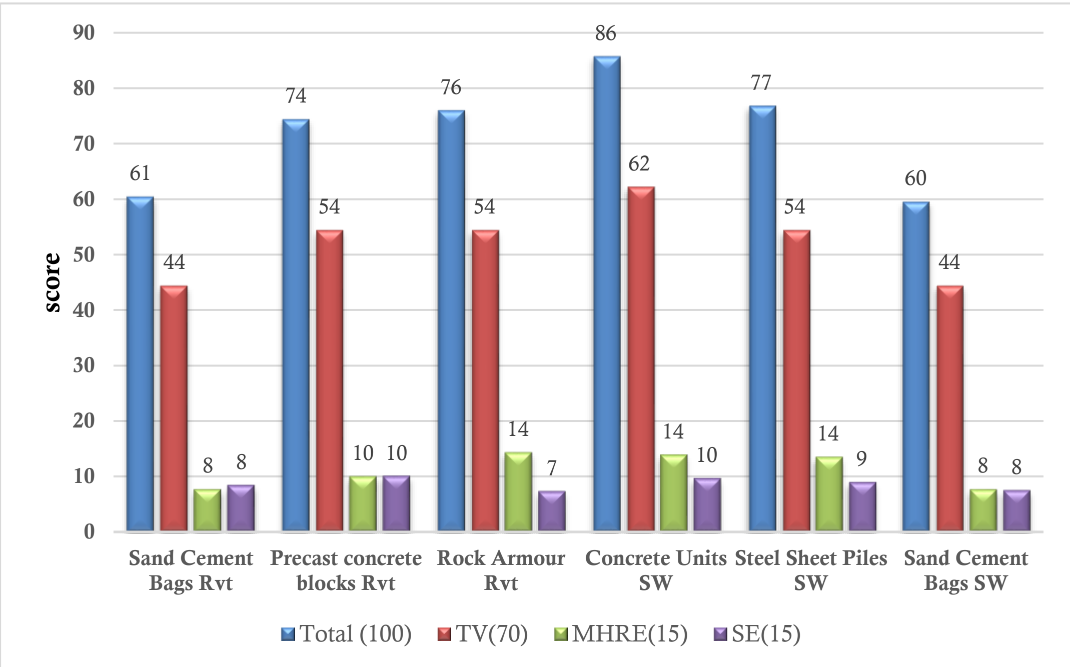


Figure 8-8 Technical evaluation scores of measures under the action 'fix coastline defence position' in Kulhudhuffushi

The measures that score technical evaluation of over 70% were then selected for further evaluation.

STAGE 5: Financial Evaluation of Feasible Measures

Using the formulae for financial evaluation in Chapter 7, the financial feasibilities of the selected measure are calculated and ranked. Table 8-6 shows the financial evaluation of the measures that scored over 70% in the technical evaluation. Figure 8-9 and Figure 8-10 depicts these results for the actions ‘protect against wave direct attack’ and ‘fix coastline defence position’ respectively.

Table 8-6 Financial evaluation of measures that scored highest in Technical evaluation in Kulhudhuffushi

Policy	**Action**	**Technical Category**	**Measure (x)**	**Capital Expenditure(I)/lm (MVR)**	**Interval of maintenance (yrs)**	**Frequency of Maintenance within design life (*Fmain*)**	**Proportion of maintenance / period (*Pmain*)**	**Design Life (*Dlife*) (yrs)**	**Total Cost (TC)/lm (MVR)**	**Average Total Cost /lm/year (MVR)**	**Rank**
HL	*Protect Against wave direct attack*	Breakwater	Rock Armour	37,000	10	5	0.05	50	46,250	925	1
			Tetrapods	71,859	20	2.5	0.05	50	80,841	1,616	4
			Geobags	23,953	5	20	0.20	15	38,324	2,555	5
			Caisson	36,000	15	2.93	0.05	44	41,280	938	3
			Steel Sheet piles	40,000	20	2.4	0.05	48	44,800	933	2
	Fix coastline defence position	Revetments	Concrete	20,360	8	3.13	0.05	25	23,541	942	4
			Rock armours	37,000	10	5	0.05	50	46,250	925	3
		Sea walls / bulkheads	Concrete	36,000	20	2.5	0.05	50	40,500	810	1
			Steel Sheet Piles	40,000	20	2.5	0.05	50	45,000	900	2

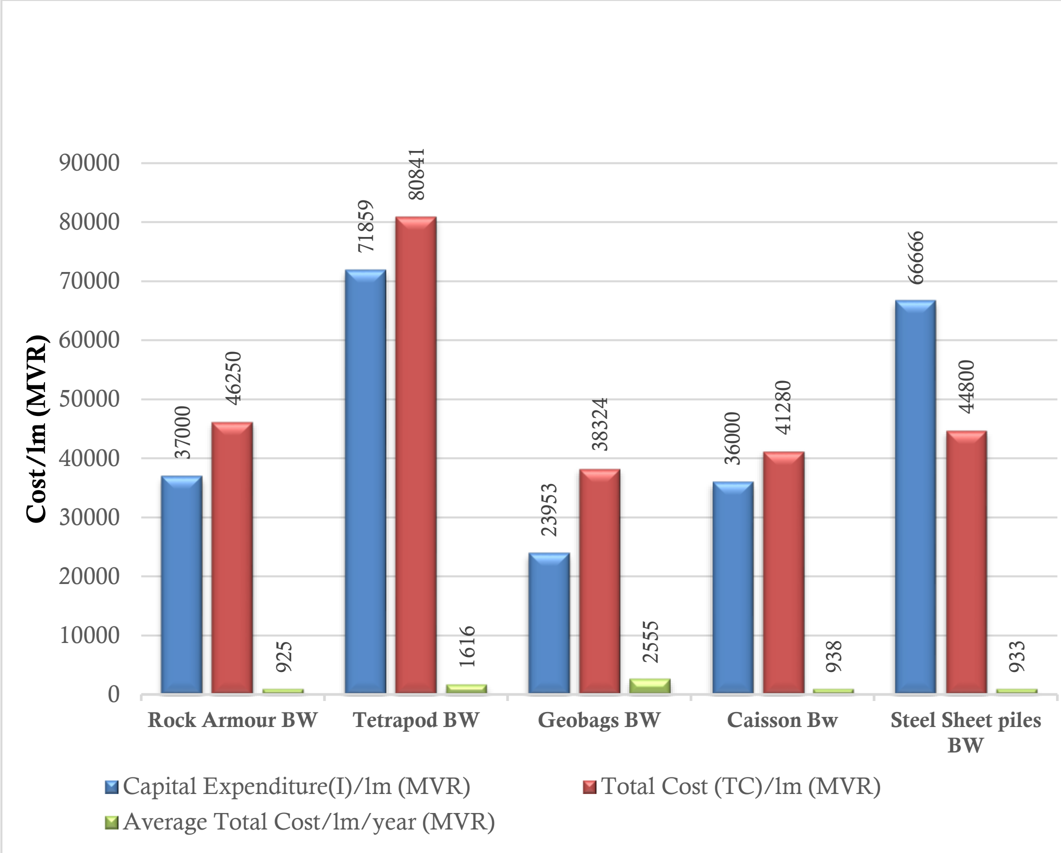


Figure 8-9 Financial cost of the measures selected under the action 'protect against wave direct attack' in Kulhudhuffushi

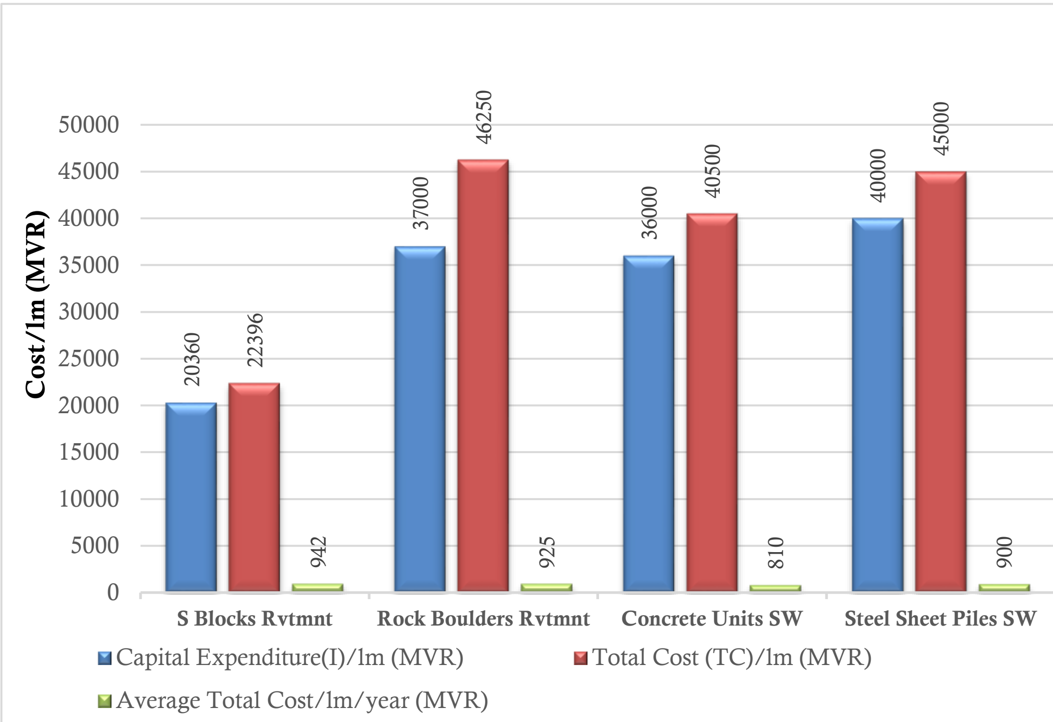


Figure 8-10 Financial cost of the measures selected under the action 'fix coastline defence position' in Kulhudhuffushi

The measures that scored the lowest financial cost (average total cost per linear meter per year) are considered financially more feasible. To combine the results for Financial and Technical evaluation, to enable a final ranking of the measures for decision making, a Financial/Technical ratio is derived by dividing the Financial cost by the Technical score. For measures with lower Financial cost or higher Technical scores, the ratio is lower and vice versa. Thus, measures that have the lowest Financial/Technical ratio are most feasible and ranked first. Table 8-7 shows the Financial/Technical ratio for measures with highest technical evaluation scores. Figure 8-11 depicts these results for the actions 'protect against wave direct attack' and 'fix coastline defence position'.

Table 8-7 Calculation of the Financial/Technical ratio and ranking of the measures that scored highest in the Technical evaluation for Kulhudhuffushi.

Policy	Action	Technical Category	Measure (x)	Technical score	Financial score	Financial / Technical	Rank
HL	Protect Against wave direct attack	Breakwater	Rock Armour	89.2	925	10.4	1
			Tetrapod	85.9	1616	18.8	4
			Geobags	69.2	2555	36.9	5
			Caisson	77.0	938	12.2	3
			Steel Sheet piles	82.2	933	11.4	2
	Fix coastline defence position	Revetments	Concrete	74.4	942	12.7	4
			Rock armours	76.0	925	12.2	3
		Sea walls / bulkheads	Concrete	85.7	810	10.0	1
			Steel Sheet Piles	76.8	900	11.7	2

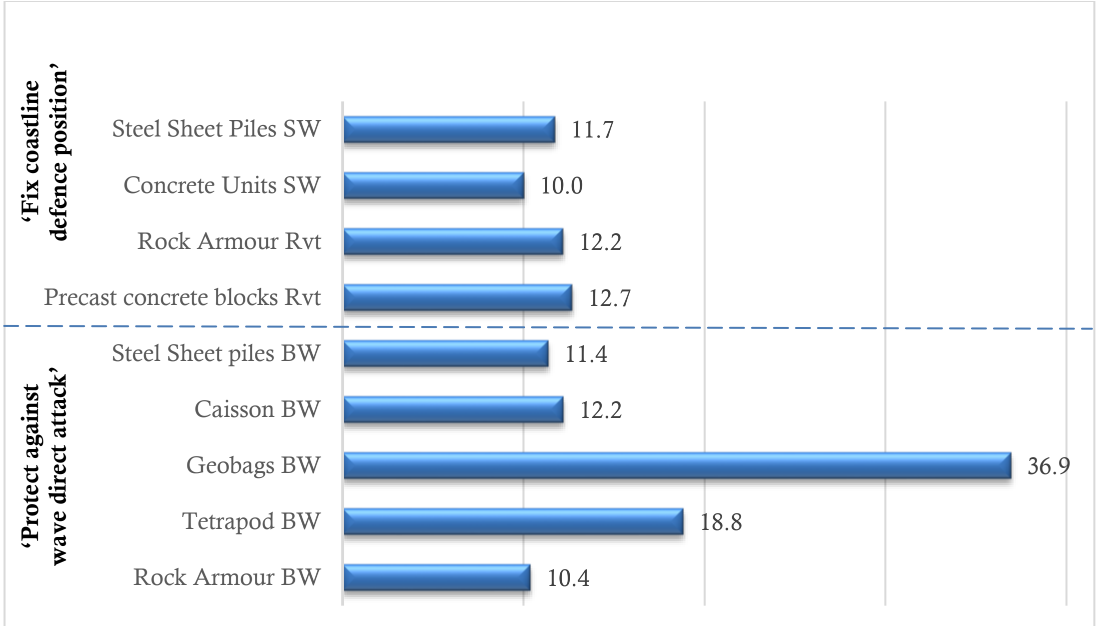


Figure 8-11 Financial/Technical ratios for the measures that scored highest in Technical evaluation for the actions 'protect against wave direct attack' and 'fix coastline defence position'

8.2.2.1 STAGE 7: Stakeholder Validation and Selection of Appropriate Measures

Based on the evaluation, the measures that had the lowest Financial/Technical ratio are preferred to be implemented. For the action 'protect against wave direct attack', rock armours breakwater can be installed towards the reef edge as it ranked highest. For the action 'fix coastline defence position', concrete seawall ranked highest.

8.3 Case Study Island 2 – GDh. Thinadhoo

8.3.1 Geographic and environmental setting

Thinadhoo is the largest island and the administrative capital of Gaafu Dhaalu atoll (GDh). The length and width of the island is 1.48km and 0.78 km respectively. The island has a 5.17km long coastline around the island. The population is 5,230 (2014 census). The closest inhabited islands are Madaveli and Hoadeddhoo on the south.

Thinadhoo was naturally formed as an elongated island but with after extensive land reclamation it is almost rectangular now. Natural land area of the island was 55ha with a wetland covering almost 30% of the total land area towards the southern end of the island. To address the land scarcity issues facing the then population, the whole of the wetland was reclaimed. In addition, the rapid population growth and the housing demand for increased migrant population from nearby islands, the island of *Maafushi*, which shares the lagoon on the north of the island, has been joined by reclamation. With the vast reclaimed land, the total land area of Thinadhoo is now 118.6ha.

The island is oriented north south direction with a very shallow reef flat of average 1 m below MSL. Thinadhoo has a reef of length 8.3km and width 2km. The average distance from coastline to reef edge is 170 m (MEE, 2013a). Thinadhoo is subject to multi-hazards threatening the coastal stability of the island. Table 8-8 shows a summary of multi-hazard incidents recorded for Thinadhoo.

Table 8-8 Summary of multi-hazard incidents recorded for Thinadhoo

Hazard category	Multi-hazards selected hazards for this study	Incidents
Geological	Earthquakes	There was no record of an earthquake in the RoM. However, stakeholders confirmed that tremors were felt from distant earth quakes in the past. The nearest source of earthquake activity is the Carlsberg ridge locates southwest of the country (UNDP, 2006).
	Coastal Erosion	Coastal erosion is observed around the island where no protection measures are placed.
Meteorological	Tropical Cyclones	11 cyclones crossed the RoM in the last 128 years (UNDP, 2006). Thinadhoo is in the area where the impact is lowest. There is no record of any cyclone events in this region. However, UNDP (2006) also states the probability of occurrence of 28-33knots cyclones is very high, and probability of cyclones of above 34 knots is high.
Hydrologic	Tsunamis	The waves overtopped on the harbour area inundated 150m in land, thus, no significant damages to the lives and livelihoods of Thinadhoo from the only tsunami recorded in the RoM in December 2004. Thinadhoo being on the western rim of the Gaafu Dhaalu atoll makes the island relatively safe and the probability of occurrence of tsunami is very low.
	Coastal Flooding (Storm surges and Swell waves)	Swells predominantly approach the RoM from southerly direction throughout the year (Young, 1999). Thinadhoo is in the least vulnerable storm surge zone, however, the island is still exposed to storm surges due to low atmospheric pressure of severe localised storm events. The western coastline is vulnerable to flooding as this side is open to ocean. Thinadhoo is exposed to wind generated waves governed by monsoonal winds. West and East coast are mostly impacted by wind generated waves in southwest and northeast monsoon respectively. Probability of storm surge occurrences is low.
Climate Change	SLR and SST	Climate change induced SLR and sea surface temperature (SST) rise would have a devastating impact on most of the islands in the RoM including Thinadhoo. The consequences would be higher for the low lying coastal areas that are prone to hazards such as flooding and tsunamis. Probability of SLR is moderate.

Figure 8-12 Erosion areas, points with severe beach erosion (BP 01-04) and cross sectional lines (A-A', B-B') of Thinadhoo (adapted from (MEE, 2013a))

Topographic assessment of Thinadhoo in Figures 8-13 to 8-15 (reproduced and adapted from (MEE, 2013a) shows cross sectional view of the island, and beach profiles from areas experiencing erosion.

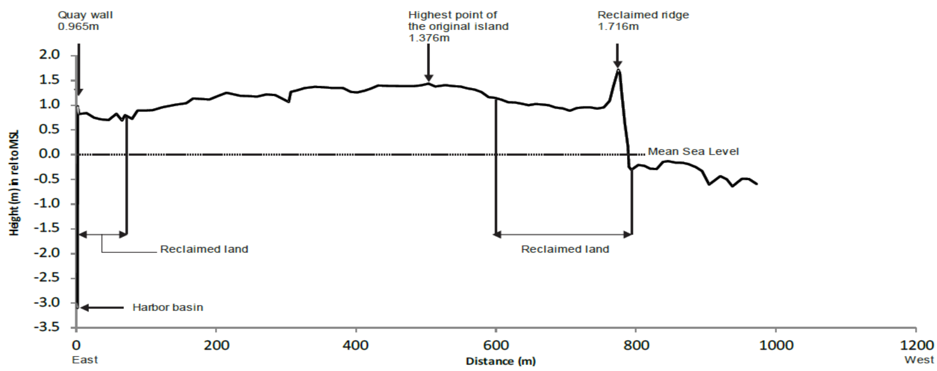


Figure 8-13 Cross sectional view A'-A of Thinadhoo

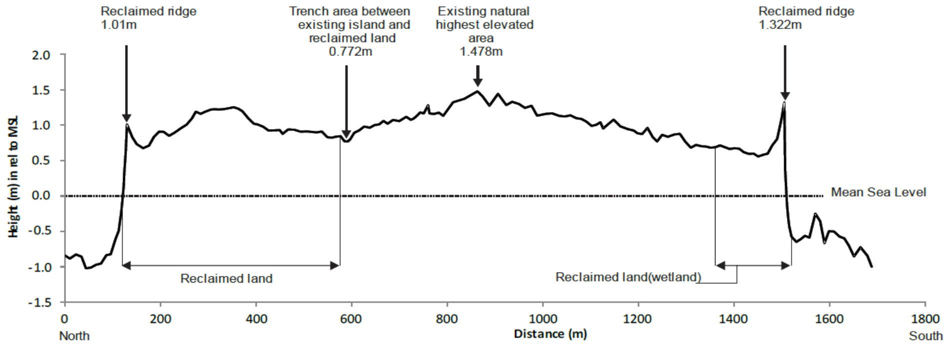
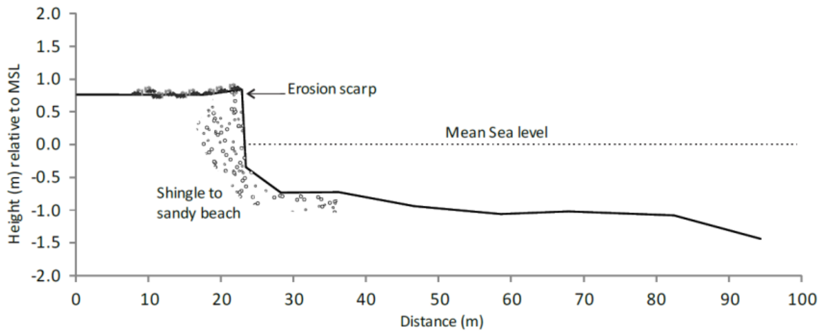
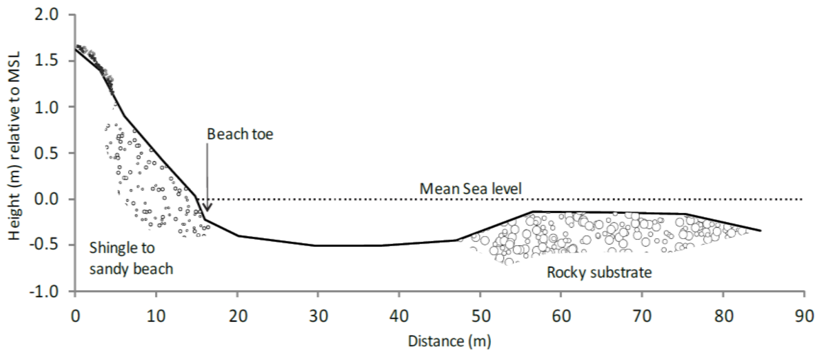


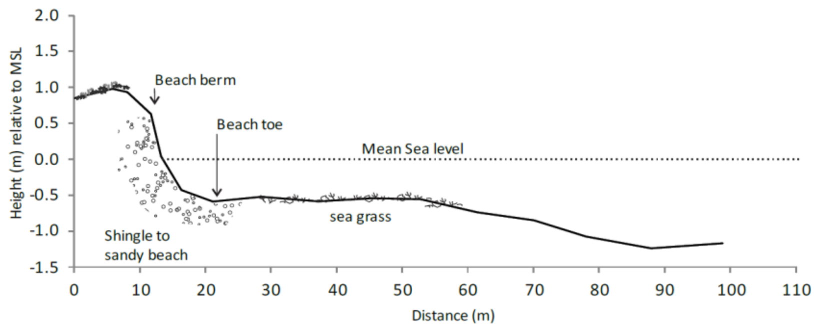
Figure 8-14 Cross sectional view B-B'of Thinadhoo



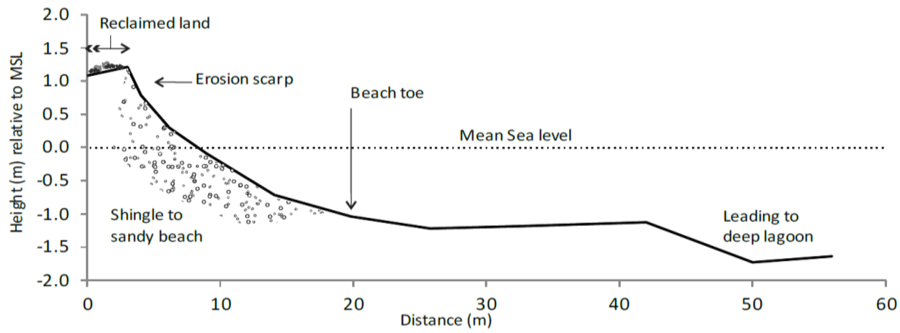
Cross section at point BP01



Cross section at point BP02



Cross section at point BP03



Cross section at point BP04

Figure 8-15 Cross sectional views of the beach profiles at selected points of severe erosion in Thinadhoo

8.3.2 Application of THOSHI for Thinadhoo

STAGE 1: Define Coastal Protection Problem

The eastern coastline of Thinadhoo has undergone significant modifications over the years while the western shoreline remains unchanged. Thinadhoo is one of the first islands where reclamation was done in the RoM. Thinadhoo has been merged with *Maafushi* Island on its north by reclamations. Vegetation is seen only in the northern coastline of Thinadhoo (MEE, 2013a). Absence of a vegetation belt on most of the coastline makes the island susceptible to occasional flooding, swell waves and surges. Thinadhoo is highly urbanized, and beaches are only seen as narrow strips on the south and south-east side.

After a thorough visual observation of the problem areas and stakeholder engagement to identify the current erosion trend, frequency and severity of erosion, and the effectiveness of the existing protection measures, the following coastal protection problems are defined.

Problem definition 1: Western coastline is susceptible to flooding due to the low lying nature of the inland area (A'), and the probability of swell waves and storm surges projected in the area is significant (MEE, 2013a). Absence of natural ridges makes it more vulnerable (BP03). Erosion is reported as seasonal but severe in this area especially on the reclaimed land.

Problem definition 2: The north-eastern shoreline where a boat repair yard is currently in operation, experiences severe coastal erosion. The area was reclaimed previously and is inclined towards inland, making the settlement close to the coastline more susceptible to flooding or tsunami (BP04).

Problem definition 3: Erosion on the south corner of the island is critical. The settlement seen in this area is mostly built on the reclaimed land from the old wetland (B'). The reclamation level is very low hence requires this area to be protected. There is a narrow strip of reef flat seaward of the coastline (BP02).

STAGE 2: Determine Policy Options and Identify Desired Action(s)

Several policy options are considered to start with and Table 8-9 shows an analysis of various policies and the rationale for selecting specific policies.

HL was the policy selected for the problems 1 and 3 with 'fix coastline defence position' as the desired action. Type of measure selected was HSO. For problem 2, MS and 'supply sand to beach' were the policy and action preferred as there is growing demand for additional land for both housing and development needs. An additional policy HL and 'fix coastline defence position' was selected to keep the reclaimed land protected. Therefore, the type of measures preferred was NCO.

Once the problem is identified, appropriate policies and actions to address the problem can then be selected. The facts of the problem identified in stage 1, such as severity of the problem and the geography of the site, will feed the decision on what policy and subsequent action is chosen.

Table 8-9 Policies and actions selected for Thinadhoo in Stage 2 and their rationale

Problem Definition	Policy		Action	Details
	Selected	**Rejected**	**Preferred**	
1. **Western coastline is susceptible to flooding due to the low-lying nature of the inland area, and the probability of swell waves and storm surges projected are significant.**	**HL**		Fix coastline defence position	Coastline is susceptible to flooding due to the low lying nature of the inland area (A'), and the probability of swell waves and storm surges projected in the area is significant (MEE, 2013a). Absence of natural ridges makes it more vulnerable (BP03). Erosion is reported as seasonal but severe in this area especially on the reclaimed land. A considerably wider and shallow reef flat is observed in this area mostly covered in sea grass. Although erosion is reported severe in Hulhangu season, 'protect against wave direct attack' for the time being is not considered as the reef flat is shallow and wide,. However, the possibility of further erosion of the coastline if unattended requires 'fix coastline defence position'. Therefore, a coastal protection measure that will restore and maintain the ridge needs to be implemented. Local stakeholders specifically requested for a measure that would trap and accrete sand and thus would form a beach for recreation in the future. They also desired construction to be started as soon as possible and discouraged novel measures to be used.
		DN		Risk will increase further if unattended
		MR		No space inland for the coastal facilities and population to move inward.
		LI		Monsoonal weather change is too severe for limited intervention
		MS		Moving seaward will likely increase flooding as the western area of the island is the roughest.
2. **The north-eastern shoreline experiences severe coastal erosion.**	**MS**		'Supply sand to beach'	Although wave action is relatively moderate in this area most of the year, severe coastal erosion is observed seasonally. It has a shallow lagoon in front of the area where coastal erosion is observed. As the island needs additional land for housing and other development demands, reclamation was proposed. The

				area was reclaimed previously and is inclined towards inland, making the settlement close to the coastline more susceptible to coastal flooding. Therefore, ‘fix coastline defence position’ is also suggested with reclamation.
		DN		Issue is too severe for doing nothing
		MR		No space inland for the coastal facilities and population to move inward
		LI		Problem too severe for limited intervention
		HL		The lagoon is very wide and shallow, HL is not recommended. Also, if the coastline is fixed in this area it would be considered a waste of resources.
3. **Erosion on the south corner of the island is severe.**	**HL**		Fix coastline defence position	The area is experiencing severe erosion throughout the year. The settlements built on the reclaimed land from the old wetland are subjected to seasonal flooding mostly due to the very low reclamation level. There is a narrow strip of reef flat seaward of the coastline. ‘Fix coastline defence position’ is suggested as further erosion would increase vulnerability of flooding.
		DN		Risk will increase further if unattended
		MR		No space inland for the coastal facilities and population to move inward.
		LI		Monsoonal weather change is too severe for limited intervention
		MS		Moving seaward will likely increase flooding as it will bring coastline closer to deep sea.

STAGE 3: Select Probable Measures

The policies and actions selected leading to the types of measures, and the pathways to probable measures are shown in the Table 8-10. This gives the decision makers a range of different measures to choose from and a clear justification of the selection.

Table 8-10 Pathways to identify probable measures for the policies and actions selected in Stage 2 for Thinadhoo

Problem	Policy	Action	Type of measure			
			HSO	SSO	NSO	NCO
1 & 3	**HL**	Fix coastline defence position	Seawalls, Revetments	NA SSO's are generally not capable of fixing the coastline position.	NA Fixing coastline in position requires structural means hence NSO's cannot be applied.	Seawall + Revetment
2	**MS**	Supply sand to beach	NA	Reclamation	NA	Reclamation + Seawall, Reclamation + Revetment

The existing coastal protection measures or mitigation action in the problem areas are ineffective. Therefore, all the probable candidates were evaluated.

STAGE 4: Technical Evaluation of Feasible Measures

Using the respective formulae for technical viability (TV), multi-hazard resiliency (MHRE), and socio-aesthetics and environmental acceptability (SE) in Chapter 7, the scores for each measure are calculated and ranked. Table 8-11 shows the results of technical evaluation of the measures.

Table 8-11 Technical evaluation scores and ranking of probable measures for Thinadhoo

Problem	Policy	Action			Score				Rank
1 & 3	HL		**Technical Category**	**Measure (x)**	**TV (70)**	**MHRE (15)**	**SE (15)**	**Total (100)**	
		Fix coastline defence position	Revetments	Sand Cement Bags Rvt	44.4	9.0	8.4	61.8	5
				Concrete	54.4	9.5	10.0	73.9	4
				Rock armours Rvt	54.4	14.2	7.3	75.9	2
			Sea walls / bulkheads	Concrete	62.2	12.8	9.6	84.6	1
				Steel Sheet Piles SW	54.4	12.1	8.9	75.4	3
				Sand Cement Bags SW	44.4	9.0	7.5	60.9	6
2	MS	*Supply sand to beach*	**Technical Category**	**Measure (x)**	**TV (140)**	**MHRE (30)**	**SE (30)**	**Total (200)**	
			Combined Approach w/ Reclamation	Recl+ Concrete Unit SW	91.1	21.3	23.0	135.4	1
				Recl+ Steel Sheet Piles SW	83.3	20.6	22.3	126.2	3
				Recl+ Sand Cement bags SW	73.3	17.5	20.9	111.7	6
				Recl+ Sand Cement bags Rvt	73.3	17.5	21.8	112.6	5
				Recl+ Concrete Rvt	83.3	18.0	23.4	124.7	4
				Recl+ Rock armours Rvt	83.3	22.7	20.7	126.7	2

For Problems 1 and 3, technical evaluation shows the concrete seawalls, rock armour revetments, and steel sheet piled seawalls are the top three most technically feasible measures (Figure 8-16). For Problem 2, the top three measures are reclamation combined with concrete seawalls, rock armour revetment, and steel sheet piled seawalls (Figure 8-17).

The measures with technical evaluation score of over 70% are selected for further evaluation.

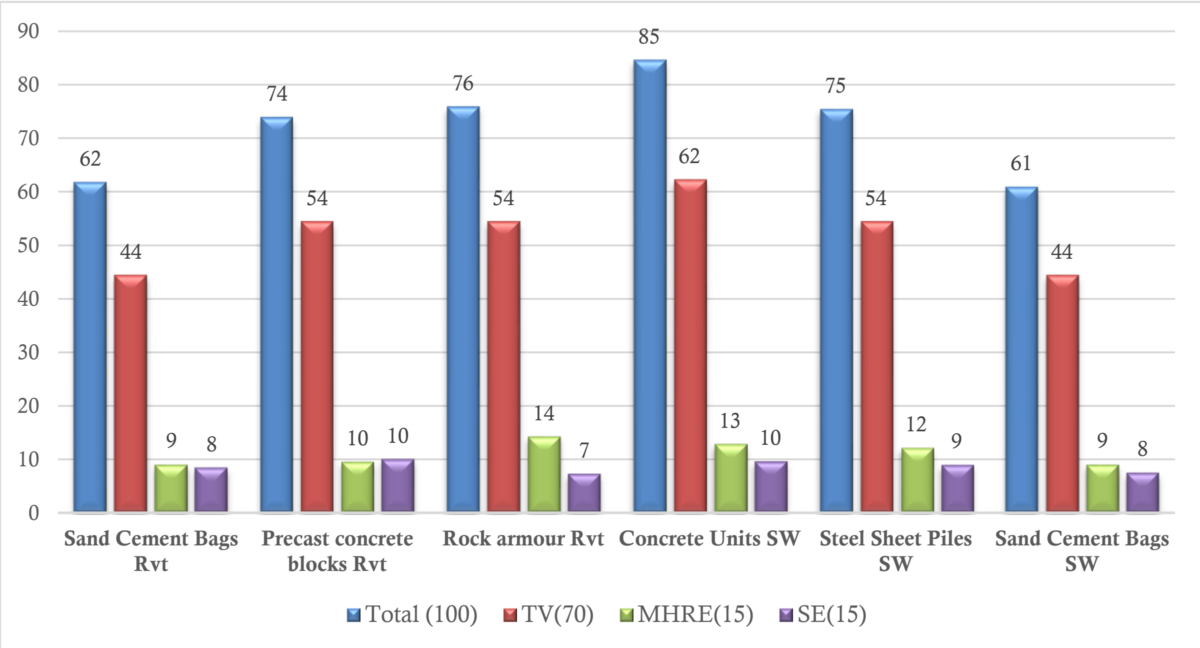


Figure 8-16 Technical evaluation scores of probable measures for problems 1 and 3 for Thinadhoo

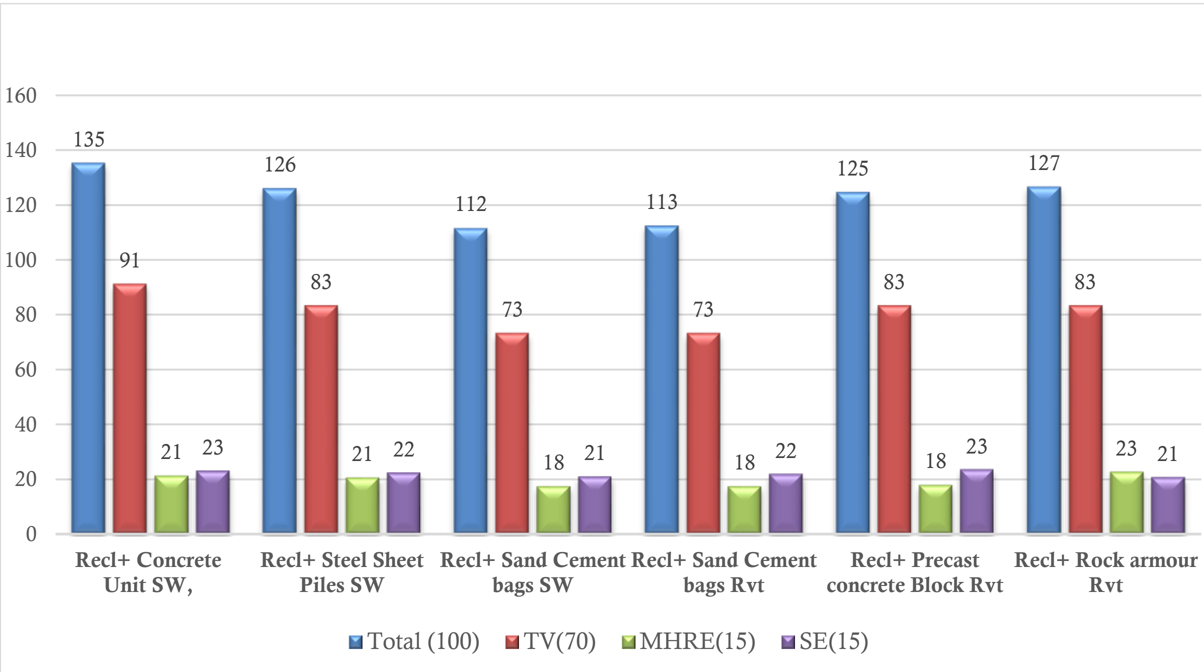


Figure 8-17 Technical evaluation scores of probable measures for problem 2 for Thinadhoo

STAGE 5: Financial Evaluation of Feasible Measures

Using the formula for financial evaluation in Chapter 7, the financial feasibilities of the measures that scored over 70% in the technical evaluation were calculated and ranked (Table 8-12).

Figure 8-18 shows financial evaluation of the measures selected for Problem 1 & 3. Figure 8-19 shows financial evaluation of the measures selected for Problem 2.

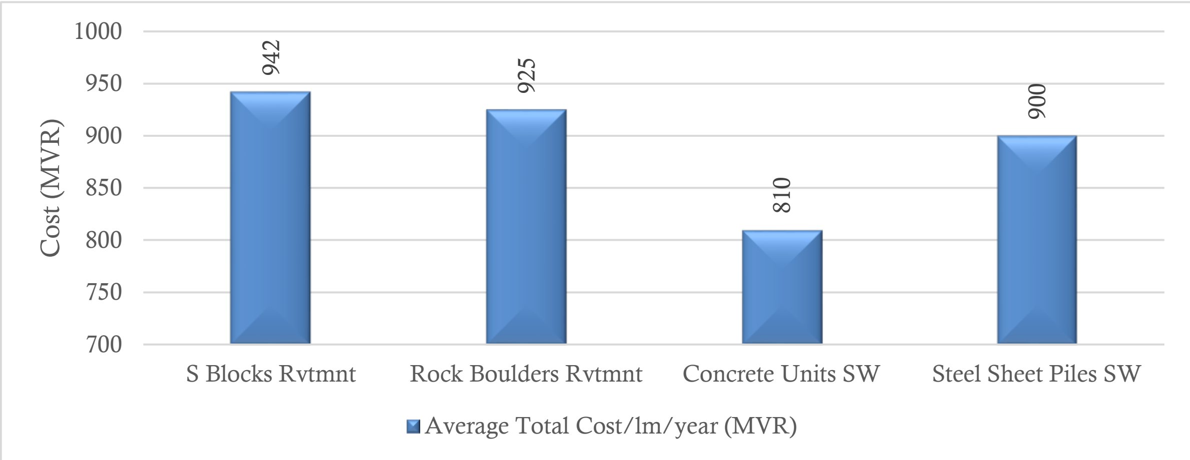


Figure 8-18 Financial evaluation of measures that scored highest in Technical evaluation for problem 1 and 3 in Thinadhoo

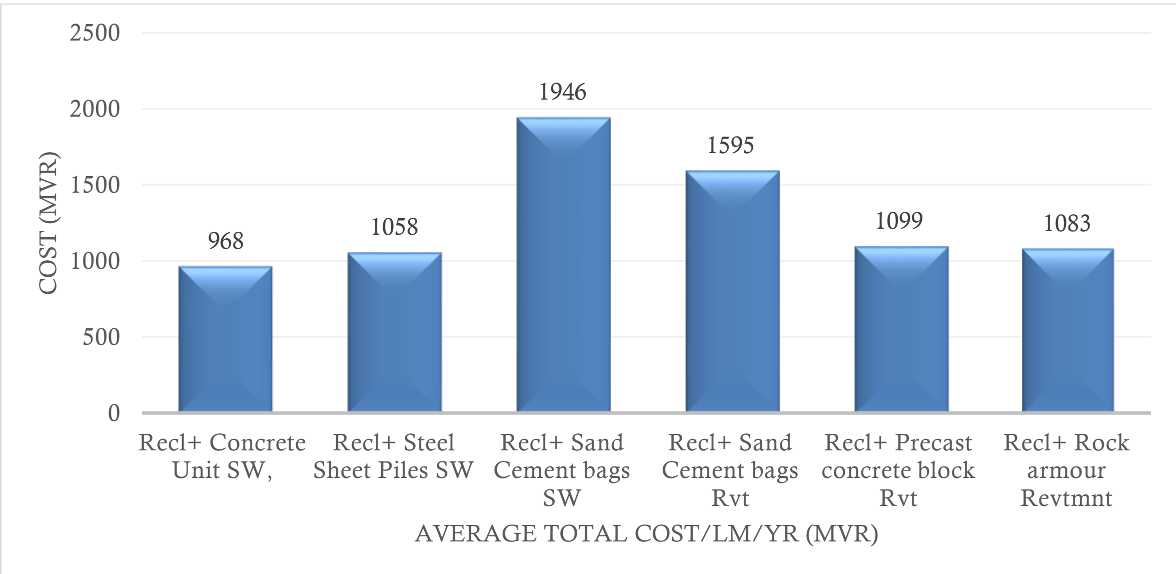


Figure 8-19 Financial evaluation of measures that scored highest in Technical evaluation for problem 2 in Thinadhoo

Table 8-12 Financial evaluation of measures that scored highest in Technical evaluation in Thinadhoo

Problem	Policy	Action	Technical Category	Measure (x)	Capital Expenditure (I)/1m (MVR)	Interval of maintenance (yrs)	Frequency of maintenance (Fmain)	Proportion of maintenance / period (Pmain)	Design Life in yrs	Total Cost (TC)/1m (MVR)	Average Total Cost/1m/year (MVR)	Rank
1 & 3	**HL**	Fix coastline defence position	Revetments	Concrete	20,360	8	3.13	0.05	25	23,541	942	4
				Rock armours	37,000	10	5	0.05	50	46,250	925	3
			Sea walls / bulkheads	Concrete	36,000	20	2.5	0.05	50	40,500	810	1
				Steel Sheet Piles	40,000	20	2.5	0.05	50	45,000	900	2
2	**MS**	Supply sand to beach	Combined Approach w/ Reclamation	Recl+ Concrete Unit SW	36,450	20	2.5	0.05	50	41,288	968	1
				Recl+ Steel Sheet Piles SW	40,450	20	2.5	0.05	50	45,788	1,058	2
				Recl+ Sand Cement bags SW	12,375	2	5	0.1	10	18,675	1,946	6
				Recl+ Sand Cement bags Rvt	10,035	2	5	0.1	10	15,165	1,595	5
				Recl+ concrete	20,810	8	3.13	0.05	25	24,329	1,099	4
				Recl+ Rock armours Rvt	37,450	10	5	0.05	50	47,038	1,083	3

For Problem 2, reclamation is combined with other possible combination options. The capital expenditure (I) is taken as the total capital expenditure of the two measures (i.e. reclamation and the concrete unit seawall etc). Reclamation in this case is a one-off measure since the combined measures will act as the primary defence barrier between reclaimed land and sea. Therefore, maintenance cost of reclamation is not taken for the Total Cost (TC) calculation. Additionally, the design life of reclamation is ignored in calculating the average total cost (ATC) as reclamation is treated as a one-off measure.

To get a final ranking of the measures, Table 8-13 calculates the Financial/Technical ratio and presents the final rankings for the measures. The measures with highest ranking are then evaluated and presented to stakeholders for validation. Figure 8-20 and Figure 8-21 show the Financial/Technical ratio of the measures selected for Problem 1 and 3 and Problem 2 respectively.

Table 8-13 Calculation of the Financial/Technical ratio and ranking of the measures that scored highest in the Technical evaluation for Thinadhoo

Problem	Policy	Action	Technical Category	Measure (x)	Technical score	Financial score	Financial / Technical	Rank
1 & 3	HL							
		Fix coastline defence position	Revetments	Concrete	73.9	942	12.7	4
				Rock armours	75.9	925	12.2	3
			Sea walls / bulkheads	Concrete	84.6	810	9.6	1
				Steel Sheet Piles	75.4	900	11.9	2
2	MS	*Supply sand to beach*	Combined Approach w/ Reclamation	Recl + Concrete Unit SW	135.4	968	7.1	1
				Recl + Steel Sheet Piles SW	126.2	1058	8.4	2
				Recl + Sand Cement bags SW	111.7	1946	17.4	6
				Recl + Sand Cement bags Rvt	112.6	1595	14.2	5
				Recl + Concrete	124.7	1099	8.8	4
				Recl+ Rock armours Rvt	126.7	1083	8.5	3

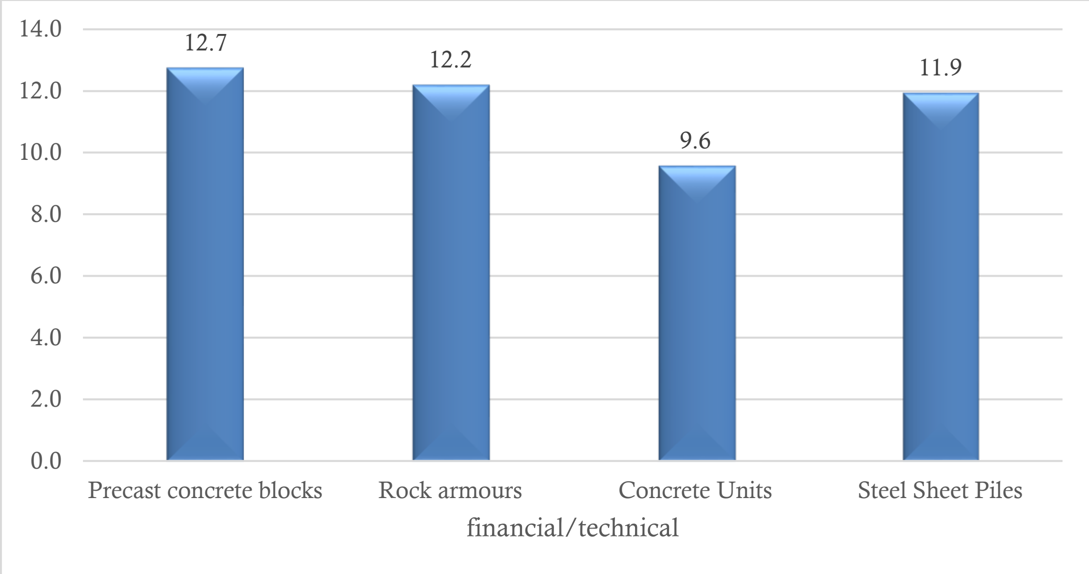


Figure 8-20 Financial/Technical ratios for the measures that scored highest in Technical evaluation for the Problems 1 & 3 in Thinadhoo

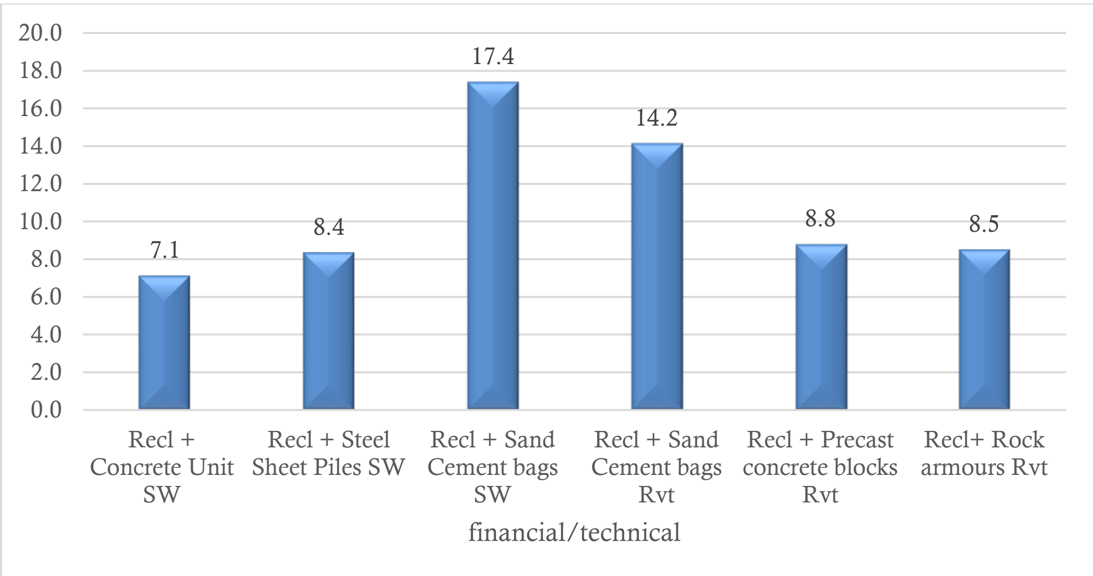


Figure 8-21 Financial/Technical ratios for the measures that scored highest in Technical evaluation for Problem 2 in Thinadhoo

8.3.2.1 STAGE 7: Stakeholder Validation and Selection of Appropriate Measures

Concrete seawall units are evaluated to be the most feasible measure for both problem 1 and 3. However, as the stakeholders preferred a measure that would trap and accrete sand and thus would form a beach in the future, seawall options for problem 1 were ignored. Therefore, the most feasible option except seawall, that is rock armour revetment, is recommended for problem 1.

Reclamation area protected with concrete seawall units are the most feasible measure hence is recommended for Problem 2.

For Problem 3, there were no additional requirements or preferences from the community on the type of measure to be implemented. Therefore, concrete seawall unit is recommended as it is the most feasible measure evaluated.

8.4 DISCUSSION

The outcome of THOSHI evaluation shows the most feasible measure for both case study 1 and 2 under the action 'fix coastline defence position' is concrete seawalls. The ranking of the measures remain constant for both the case studies since the only variable in THOSHI evaluation is the MHRE which is only 15% for the factor, and there is no significant difference in multi-hazards scores between the islands. The ranking shows that in these cases the technically best measures are also the financially feasible measures.

In Case Study 1 (Kulhudhuffushi), for the action 'protect against wave direct attack', breakwater with rock armour, steel sheet piles and concrete caisson are the top three feasible measures. However, the second most feasible measure would have been tetrapod if the decision was made on technical evaluation alone. The ranking shows that, apart from rock armour breakwater, technically best measures are not the most feasible financially.

For the problems identified in Kulhudhuffushi, a rock armour breakwater has been installed for Problem 1 to 'protect against wave direct attack'. No other measures have been installed or proposed for Problem 2 or policy 'fix coastline defence position' of Problem 1. Table 8-14 shows the results for the proposed solutions and the measures proposed by THOSHI for Kulhudhuffushi.

Table 8-14 Comparison of implemented and proposed measures by THOSHI for Kulhudhuffushi coastal protection problems.

Problem	Implemented measures				Proposed measures by THOSHI			
	Measure	Technical score	Financial score	Financial/ Technical	Measure	Technical score	Financial score	Financial/ Technical
Problem 1, *Policy - 'protect against wave direct attack'*	Rock armour BW	89	925	10	Rock armour BW	89	925	10
Problem 1, *Policy - 'fix coastline defence position'*	No measures implemented or proposed	NA	NA	NA	Concrete seawall	74	942	13
Problem 2, *Policy - 'protect against wave direct attack'*	No measures implemented or proposed	NA	NA	NA	Rock armour BW	89	925	10
Problem 2, *Policy - 'fix coastline defence position'*	No measures implemented or proposed	NA	NA	NA	Concrete seawall	74	942	13

For the measures that have already been implemented in Kulhudhuffushi, the measures are the same as those proposed by THOSHI. There is no indication in any documents that a specific measure for 'fix coastline defence position' of Problem 1 is proposed or intended in the future. However, THOSHI analysis shows that a single policy of 'protect against wave direct attack' is insufficient for both problem areas since wave action is severe and current coastal ridge needs to be protected against further deterioration.

For all the problems identified in the Case Study 2 (Thinadhoo), measures have recently been implemented. The area in Problem 1 was protected with a sand-cement bag revetments installation. The area identified in the Problem 2 was reclaimed and the new land was protected with a rock armour revetment. A rock armour revetment was also constructed for the Problem 3. Table 8-15 compares the evaluation results for the implemented solutions against those proposed by THOSHI for problems identified in Thinadhoo.

Table 8-15 Comparison of implemented and proposed measures by THOSHI for Thinadhoo coastal protection problems.

Problems and the policies	**Measures Implemented**				**Proposed measures by THOSHI**			
	Measure	**Technical score**	**Financial score**	**Financial/ Technical**	**Measure**	**Technical score**	**Financial score**	**Financial/ Technical**
Problem 1, Policy - *'fix coastline defence position'*	Sand-cement bag revetment	61.8	1438	23.3	Rock armour Rvt	75.9	925	12.2
Problem 2, Policy - *'Move Seaward'*	Recl+Rock armour Rvt	126.6	1083	8.6	Recl+ Concrete SW	135.4	968	7.1
Problem 3, Policy - *'fix coastline defence position'*	Rock armour Rvt	75.9	925	12.2	Concrete SW	84.6	810	9.6

If THOSHI was applied, the results would have been different for all the three problems identified in Thinadhoo. With the added stakeholder requirement to develop a beach in this area, the solution for Problem 1 would have been rock armour revetment. This is a better solution both technically and financially than the measure implemented, which is sand-cement bag revetments. Rock Armour revetments are more stable structurally and less susceptible to flanking due to swell waves and the storm surges in the *Hulhangu* season. Additionally, rock armour revetment would have resulted in an 84 percent cost saving for the solution, which is a significant amount.

For the Problem 2, the policy MS and action 'supply sand to beach' was implemented which was also the outcome of THOSHI. However, THOSHI would have recommended the use of concrete seawalls as opposed to a rock armour revetment to protect the reclaimed area. THOSHI shows that a concrete sea wall is marginally better technically, since a sea wall also provides access facilities, which would be an added advantage as the northern part of the island becomes more populated and people and businesses move into the reclaimed area. This would additionally have resulted in a cost saving of 12 percent per year.

The results of MS policy used in Thinadhoo also show that reclamation when combined with additional protection measure(s) increases the feasibility as it enhances the combined technical benefits consecutively and mitigates the drawbacks. Even though, the combination of concrete seawall with reclamation have been evaluated as the best measure by THOSHI, other combination option of reclamation with steel sheet pile BW, rock armour revetments, and concrete revetment are found to be very competitive in their financial versus technical feasibility. It is interesting to note that the ranking of the measures for MS shows that the technically best measures are also financially most feasible.

For the Problem 3, even though there was stakeholder desire to reclaim the area, THOSHI analysis shows that the reef edge was too close to the coastline and reclamation of this area would increase flooding and inundation and make the area more vulnerable. Thus, MS was rejected for this problem. Furthermore, to 'protect against wave direct attack' the area between the coastline and the reef edge is too narrow to install a breakwater. The outcome of THOSHI shows that concrete seawall would be the measure most feasible, while a rock armour revetment is currently installed. In contrast to the Problem 1, a rock armour revetment in region of Problem 3 increases the risk to the settlements due to their proximity to the coastline and the proximity of the coastline to the reef edge. Additionally, since there is no desire for a beach in that region and reclamation is not an option, a sea wall would save additional land area that would be lost to the installation of a revetment and result in a 12 percent cost saving.

The case study applications confirmed that application of THOSHI resulted in solutions that are not only better financially, but also help to select measures that are more resilient structurally. It also provides a more simplified, systematic and transparent way for stakeholders and the decision makers to compare various options, while taking unique stakeholder requirements into consideration. Moreover, the analysis process involved in THOSHI enables decision makers to identify areas of conflict between stakeholder needs and technical considerations and provides a systematic approach to deal with those conflicts. This is demonstrated by the cases where stakeholders wanted reclamation (Thinadhoo Problem 3) but this policy was rejected by THOSHI, in contrast to where stakeholders wanted a beach (Thinadhoo Problem 1) and this could be accommodated by THOSHI. Finally, THOSHI also helps to improve documentation, better communication and collaboration with the stakeholders.

8.5 CHAPTER SUMMARY

This chapter presented examples of the application of THOSHI using two case studies. THOSHI was utilised to systematically evaluate different measures to provide solutions to the coastal protection issues identified in the case study islands. The results confirmed the applicability of THOSHI to different islands and its capability to evaluate measures on both technical and financial aspects, and methods of combining different measures and evaluating them based on their combined costs and benefits. The analysis showed that for problems identified in Case study 1 (Kulhudhuffushi), the measures currently implemented were the same as those proposed through THOSHI, and that current solutions are inadequate for the problems identified. The analysis also showed that for the three problems identified in Case study 2 (Thinadhoo), the measures proposed through THOSHI were both technically and financially better solutions than the ones which are currently in place.

9 SUMMARY, KEY FINDINGS, AND RECOMMENDATIONS

9.1 SUMMARY

The purpose of this research was to design a DSF to aid engineers, decision makers and other relevant stakeholders in evaluating and selecting effective coastal protection measures for the RoM. The specific research objectives included:

- Identifying existing policies, regulations and documentation relevant to coastal protection decision making in the RoM and identifying gaps in policy or knowledge.
- Identifying common coastal protection measures used in the RoM and document their advantages and disadvantages.
- Understanding stakeholders' awareness of and interaction with different coastal protection measures and decision-making processes, and understanding the potential impact to the current decision making process, of increased stakeholder contribution in the formulation of strategies and decision making for coastal protection works.
- Understand professionals' perception and attitude towards the common coastal protection measures used in the RoM and identifying the parameters and factors important for coastal protection decision making.
- Conceptualising and designing a coastal protection DSF for the RoM
- Applying the DSF to selected case studies.

Coastal protection measures have been used in various forms in the RoM for several decades. Evolving designs and techniques and increases in material prices together with the increasing rate of coastal erosion has meant that coastal protection is becoming an unsustainable economic burden on the country. The increasing severity of coastal erosion, sea level rise and other climate hazards across the country also require that coastal protection measures are technically viable and capable of withstanding worsening climactic conditions. Moreover, as the population and economy develops and diversifies, it is equally important that coastal protection measures are not only economically feasible and technically viable, but also socially acceptable and catering to the needs of a transforming population. However, the politicized and ad-hoc nature of coastal protection decision making in the RoM has meant that coastal protection measures are inefficient, costly and less effective. Thus, there is a critical need for a method of systematic evaluation of protection measures to aid coastal protection decision making in the RoM.

Review of literature revealed the lack of a decision support system or framework that addresses the systematic evaluation and selection methodology for appropriate coastline protection structures depending on variable environmental and physical contexts. In the RoM, there were a few number of studies that provided some form of feedback or support for policy makers in coastal protection, but none provided a systematic approach to decision making. The 'Formulation of Guidelines for Climate Risk Resilient Coastal Protection in the Maldives' is the only document that comes close to a DSF. However, the guidelines focus on improving the design aspect of coastal protection measures to make them more climate resilient, rather than providing a framework for choosing the measures. Additionally, the review conducted on some of the coastline protection measures designed in the RoM identified that the primary objective of the designed were intended for access harbour projects and not for coastline protection (Kench, 2010). Thus, while these studies provide important information to decision makers once an appropriate coastal protection measure has been chosen, it does not support the actual process of selecting an appropriate measure.

This thesis bridges that gap by formulating a DSF for coastal protection decision making in the RoM, named 'THOSHI'. THOSHI starts with recognizing the key stages of the evaluation process, followed by identifying the most important evaluation parameters and using stakeholder survey data and literature to assign respective weights and scores for the different factors and coastal protection measures. Finally, THOSHI was applied to two case studies to validate the framework. According to the types of DSF and their descriptions adapted from various sources THOSHI has the attributes of a knowledge-oriented DSF that allows different coastal protections measures to be comparatively evaluated technically and financially. Technical evaluations are based on three parameters: technical viability, hazard resiliency and socio-aesthetic and environmental acceptability. Financial evaluation is based on capital cost, repair and maintenance costs and design life of measures. THOSHI involves seven key stages:

1. Define coastal protection problem,
2. Determine policy options and identify desired actions
3. Identify feasible measures
4. Carry out technical evaluation
5. Carry out financial evaluation
6. Conduct cost-benefit analysis (optional)
7. Validate with stakeholder and select appropriate measure(s).

This research also collates and augments existing information about the coastal protection measures in RoM, including decision making processes and policies.

9.2 KEY FINDINGS

9.2.1 Coastal Protection Measures in the Republic of Maldives

- Review of different coastal protection techniques in RoM revealed that hard structural options such as rock armour breakwaters, revetments and sea walls are the most commonly used type of coastal protection measures in the RoM. The most frequently used soft options were reclamation and beach nourishment. Combined approaches either with soft and hard measures or two or more hard measures are becoming popular in most parts of the RoM, and are proven to be effective by mitigating their combined drawbacks while merging their respective benefits. The propensity to use hard options is backed by the survey of local stakeholders and professionals. Although several researchers advocate against the use of hard coastal protection measures, most of these studies are based on coastlines that are geo-physically very different to that of RoM or have a purely environmental impact focus rather than a coastal protection focus. Additionally, the cases of accelerated coastal erosion and negative environmental impacts identified in some cases after implementing hard structural options are not the result of the structures itself but the design and implementation of improper coastal protection measures. Furthermore, most of the coastal protection measures currently being used in the RoM have been adopted from other countries with vastly different geophysical environments and most of the measures have not been customized to the country's coastlines and environment.

- Literature on the types of coastline protection measures in the RoM was fragmented at best and in some cases non-existent. Some of the important data on commonly used measures specific to the country are not available in any published literature. This study narrowed the formal literature gap by supplementing existing information about coastal protection measures in RoM with the vast amount of research done on the same systems in other countries, especially countries with similar environmental features and evaluated the most common systems used in RoM according their advantages and disadvantages.

9.2.2 Institutional and Policy Framework

- The current institutional set up for coastal protection in the RoM is ineffective and weak. The mandate of coastal protection is scattered and overlaps across several government and local agencies and the role of local agencies in coastal protection is particularly ambiguous. The local communities have no capacity in terms of financing or human resources to protect and manage their own coastlines and thus, have to rely on central government resources, which severely limits the decision making power of local stakeholders.

- A critical gap in the policy and regulatory framework is that there is no existing policy, guideline or regulation in force, that explicitly addresses coastal protection works in RoM. Other environmental, infrastructure or related policies, guidelines and regulatory measures are also highly insufficient in addressing the impact of human interventions on the coastlines and vital areas such as selection of measures, repair and maintenance, and sustainability of the systems installed are not addressed in any official documents. Moreover, the existing institutional and policy framework is ineffective in monitoring and evaluating performance of implemented measures on the coastlines. No system exists to collect and manage data and information about the performance of measures once they are installed, and thus there is limited scope for improving the decision making process or the coastal protection measure designs through past experience.

9.2.3 Stakeholder Perception about Coastal Protection

- Investigation of stakeholder understanding of and attitudes towards various coastal protection measures and processes in the RoM revealed that only a small proportion of local stakeholders get the opportunity to contribute, in any form, to the coastal protection decisions and most local stakeholders were not satisfied with the way their island coastlines are managed and protected. On the other hand, most local stakeholders exhibit sufficient understanding of the local coastal protection issues and basic knowledge of common coastal protection measures used in the RoM. All the islands surveyed had some individuals who were particularly knowledgeable about the local coastal issues, including extensive awareness of local environmental problems, and a good recall of historical coastal protection issues. Since most of this knowledge is not systematically collected or recorded in RoM, this demonstrates that the local residents can be a vital source of information in coastal protection decision making processes. This inference was backed by most professionals, except for a few in the government sector who had reservations about the lack of technical knowledge and the delays to implementation and possible local political influences to decisions if local stakeholders are involved. This study found that there is a way to capitalize on local stakeholder knowledge and mitigate the negative impacts of their involvement by limiting their involvement to specific stages of decision making.

- Both local and professional stakeholders believe that their coastal problems cannot be solved with soft options exclusively and that there is a strong need to make the coastal protection measures more structurally resilient than aesthetically pleasing. Moreover, they consider ‘Do nothing’ and ‘managed re-alignment’ to be impractical to the RoM due to the geo-physical setting of the islands and that 'Hold the line', 'move seaward', and 'limited intervention' are the coastal management policies most suitable to the RoM.

9.2.4 Decision Support Framework

- There are no coastal protection DSFs currently in use in the RoM and the professionals surveyed agree that the politicized and ad-hoc nature of decision making processes worsens resources duplication, creates difficulties in project implementation, and leads to the installation of inappropriate measures which subsequently deteriorates the condition of the coastline leading to increased cost implications and escalated coastal protection and other environmental problems. The selection of measures are non-systematic and based on the limited knowledge and understanding of a small group of decision makers in the central government. While crucial for decision making, the social costs and benefits, financial costs, maintenance costs and durability of various measures are poorly addressed in decision making. Furthermore, the highly targeted nature of coastal protection measures in the RoM, while fixing the problem in the locality it is targeted to, also leads to exacerbation of coastal erosion, inundation and hazard exposure in nearby areas. A holistic approach of coastal protection is needed to minimize these socio-economic and environmental impacts to nearby areas. Consequently, a coastal protection DSF that evaluates measures based on technical and financial feasibility is vitally important for the RoM to ensure the efficient selection of appropriate coastal protection measures.

- The decision support framework THOSHI that was developed in this study, makes the decision making process systematic, fact-based, transparent, and utilizes local stakeholder knowledge in a way that enhances the decision making process without hindering the application of technical expertise. The most important parameters for technical evaluation as identified in the literature and the professionals' survey, which were technical viability, multi-hazard resiliency and socio-aesthetic and environmental acceptability, are used to evaluate measures. There is no specific optimum weights for technical parameters as evidenced by literature and professionals' opinions. However, from the three parameters selected for THOSHI, the order of importance descends from technical viability, followed by multi-hazard resiliency to socio-aesthetics and environmental acceptability. The exact weightage of each parameter can be adjusted from case to case depending on the environmental and geographic conditions, hazard exposure and resource availability.

- While climate change is more abstract, the symptoms of climate change that occur as changes in hazard severity and patterns are much easier to notice and measure. A significant aspect of THOSHI is that it factors in multi-hazard resiliency into the technical evaluation process and as such, enables the decision making process to be sensitive to climate change.

- The results of the case studies confirmed the applicability of THOSHI to different islands and its capability to evaluate measures on both technical and financial aspects, and methods of combining different measures and evaluating them based on their combined costs and benefits. The analysis showed that for problems identified in Case study 1 (Kulhudhuffushi), the measures currently implemented were the same as those proposed through THOSHI, and that current solutions are inadequate for the problems identified. The analysis also showed that for the three problems identified in Case study 2 (Thinadhoo), the measures proposed through THOSHI were both technically and financially better solutions than the ones which are currently in place.

9.3 RECOMMENDATIONS

- Inadequate island level data and records on the development of coastal protection measures, the changes brought to those systems over the years, or the environmental impact from those interventions make it hard to effectively gauge coastal protection measures on the islands in RoM, and to sort out the best evaluation parameters. Furthermore, the lack of scientific data and research on the effectiveness and performance of different measures in a coral reef environment and mapping resiliency of CP measures to hazards are some of the limitations. An information system that regularly collects these data at the local level, and geomap data on the impact to coastlines before and after the installation of coastal protection measures and financial data at the central level, will enhance the DSF and make decision making significantly more evidence-based. Furthermore, impact of coastal protection measures in a coral reef environment using this type of data to evaluate their effectiveness and performance will be an interesting area for further research.

- In a context where limited records or data are kept about important parameters, local level stakeholder involvement is even more critical. However, the reservations of professionals in government agencies show that local level stakeholder involvement can possibly lead to delays in decision making and project implementation and introduce unnecessary bias into decisions due to local politics. Thus, it is important that local level stakeholders are involved where they can contribute best. When using THOSHI, it is recommended that local stakeholders be more involved in Stages 1 (Define Coastal Protection Problem), Stage 2 (Determine Policy Options and Identify Desired Actions) and Stage 7 (Stakeholder Validation and Selection of Appropriate Measures).

- Overlapping mandates and ambiguous regulations and policies that currently lead to duplication and wastage of resources and inefficiency can be reduced by better delineation of mandates between government agencies, clarifying policies, and developing policies to address serious gaps in policy such as maintenance and repair.

- The current allocation of the technical parameter weights in THOSHI favours technical viability significantly more than the others. This was based on the limited published data specific to RoM, author's and other professionals' professional judgment. These weights can be adjusted to fit the case or context THOSHI is being applied to and more research and data on these parameters would lead to a more fine-tuned and reliable set of weights. While it is important that in most cases, technical evaluation not be overridden by undue weight on financial evaluation, THOSHI has the flexibility to customise decision making outcomes to cater for special circumstances. And although THOSHI was specially formulated for the context of RoM, using local stakeholder preferences to guide the choice of technical parameters, the basic structure of THOSHI can in principle be applied elsewhere, where geophysical and environmental features are similar and where stakeholders interact similarly with their coasts. For such applications, the scoring parameters and weights will need to reassessed for validity.

- Customizing the coastal protection systems developed in, and adopted from, environments that are vastly different from that of RoM is an important area for further research. This will allow engineers to evaluate measures that work and do not work in the RoM context. It will also be beneficial to then develop a manual for engineers on how to bring modifications to borrowed designs, which will enable them to effectively build on existing experience.

- THOSHI outlines stages where information inputs are needed and outputs are generated. These inputs and outputs, if documented well can lead to better transparency of the decision making process and building a knowledge-base for subsequent projects.

- Due to the lack of information on the performance of existing coastal protection structures installed in RoM, it was impossible to compare how THOSHI performed against past decision making outcomes, in terms of foreseeing and mitigating possible problems that existing installed structures endured. This could be an area for further study.

- A proactive rather than a reactive approach to coastal protection will give the relevant authorities the time to consider measures, and identify, evaluate and select best available measures on a need basis. It will also reduce the chances of the decision making becoming politicized. Studies to scrutinize political decision making and assess the cost implications resulting from such decisions can be an important area for future study.

In conclusion, this study finds that coastal protection decision making in RoM needs a more systematic approach to reduce duplication, increase efficiency and enable the selection of appropriate measures for its varied island environments. The decision support framework, THOSHI, that has been developed in this research by using existing information and incorporating stakeholder opinions can be a valuable tool for coastal protection decision makers. If this tool is adopted, the need for data and information inputs can lead to better collection of coastal protection data and records. As coastal protection-related information and data becomes available, the tool can be refined and calibrated further to better fit the country context. In comparison to other relevant studies such as (Venton et al., 2009) and UNDP (2007) that focus mostly on the assessment of hazard implications, THOSHI provides ways of assessing TV and SE of the coastal protection measures. THOSHI also provides opportunities for stakeholder involvement in the decision making. In addition to a DSF, a better coastal protection policy and regulatory framework needs to be developed and the institutional framework needs to be strengthened to improve coastal protection decision making in the RoM.

10 REFERENCES

ADB 2010, *INDIA: Sustainable Coastal Protection and Management - PPTA Final Report*, The Asian Development Bank

Ahrens, J 1989, 'Recommendations for updating EM 1110-2-1614, design of coastal revetments, seawalls, and bulkheads', *Draft report, US Army Waterways Experiment Station, Vicksburg, MS*

Alter, S 1980, *Decision support systems: current practice and continuing challenges*

Arnott, DR 1998, 'A framework for understanding decision support systems evolution', *9th Australasian Conference on Information Systems, Sydney, Australia: University of New South Wales*

Babbie, E 2004, 'Survey research', *The practice of social research,* vol. 10, no. 1, pp. 242-280.

Bacchiocchi, F & Airoldi, L 2003, 'Distribution and dynamics of epibiota on hard structures for coastal protection', *Estuarine, Coastal and Shelf Science,* vol. 56, no. 5, pp. 1157-1166.

Banton, J, Warner, P, Smith, D & Morin, V, 'Selection of Appropriate Coastal Protection Strategies for Caribbean Coastlines'

Bard, P-Y & Riepl-Thomas, J 2000, 'Wave propagation in complex geological structures and their effects on strong ground motion', *Wave motion in earthquake eng*, pp. 37-95.

Barnard, PL, O'Reilly, B, van Ormondt, M, Elias, E, Ruggiero, P, Erikson, LH, Hapke, C, Collins, BD, Guza, RT & Adams, PN 2009, *The Framework of a Coastal Hazards Model- A Tool for Predicting the Impact of Severe Storms*, U. S. Geological Survey

Basco, D 1998, 'The economic analysis of "soft" versus "hard" solutions for shore protection: An example', *Coastal Engineering*, no. 26

Beca 2010, *Shoreline Protection Guidelines - Prepared for Government of Kiribati*, Beca International Consultants Ltd

Becker, JS 2007, *Managing our coast: the tabulated results of two community surveys undertaken at Tairua and Waihi Beach*, GNS Science.

Bezuijen, A, Klein Breteler, M & Bakker, K 1987, 'Design criteria for placed block revetments and granular filters', *Paper presented at the 2nd Copedec (Beijing, China).*

Bijker, EW 1989, 'Protection of sandy coasts', *Terra et Aqua*, no. 39, pp. 20-23.

Bird, ECF 1985, *Coastline changes : a global review*, Wiley, Chichester, New York.

Boorman, L, Garbutt, A & Barratt, D 1998, 'The role of vegetation in determining patterns of the accretion of salt marsh sediment', *Geological Society, London, Special Publications,* vol. 139, no. 1, pp. 389-399.

BOP, E 2002, *Erosion protection works , guidelines for Tauranga harbour*, Environment Bay of Plenty, Western Bay of Plenty District Council, Tauranga District Council, EBOP

Boruff, BJ, Emrich, C & Cutter, SL 2005, 'Erosion hazard vulnerability of US coastal counties', *Journal of Coastal Research*, pp. 932-942.

Bours, D, McGinn, C & pringle, P 2013, *Monitoring & evaluation for climate change adaptation: A synthesis of tools, frameworks and approaches*, SEA Change CoP, Phnom Penh and UKCIP, Oxford

Bradbury, A, Allsop, W, Latham, J, Mannion, M & Poole, A 1988, 'Rock armour for rubble mound breawaters, sea walls, and revetments: recent progress'

Bridges, T, Henn, R, Komlos, S, Scerno, D, Wamsley, T & White, K 2013, 'Coastal Risk Reduction and Resilience: Using the Full Array of Measures', *Washington, DC*

Broomfield, JP 2002, *Corrosion of steel in concrete: understanding, investigation and repair*, CRC Press.

Brunn, P 1952, 'Measures against erosion at groins and jetties', *3rd international conference on coastal engineering*, Cambridge, MA, USA

Burkett, V & Davidson, M 2012, *Coastal Impacts, Adaptation and Vulnerability: A Technical Input to the 2012 National Climate Assessment*, NOAA

Champion, DJ & Sear, AM 1968, 'Questionnaire response rate: A methodological analysis', *Soc. F.,* vol. 47, p. 335.

Charmaz, K, & Belgrave, L. L. 2007, *Grounded theory*, The Blackwell encyclopedia of sociology

Chen, X & Zong, Y 1999, 'Major impacts of sea-level rise on agriculture in the Yangtze delta area around Shanghai', *Applied Geography,* vol. 19, no. 1, pp. 69-84.

Chu, J, Yan, S & Li, W 2012, 'Innovative methods for dike construction–An overview', *Geotextiles and Geomembranes,* vol. 30, pp. 35-42.

CIRIA, C 2007, 'CETMEF. 2007. The Rock Manual. The use of rock in hydraulic engineering', *C683, CIRIA*

Cohen, A & Condeluci, CE 2014, *Decision Support Systems for Benefits: Framework and Evaluation*, Liazon Corporation, viewed, http://liazon.com/wp-content/uploads/Decision-Support-Systems-for-Benefits-Framework-and-Evaluation.pdf

Cooper, JAG & Mckenna, J 2008, 'Working with natural processes: the challenge for coastal protection strategies', *The Geographical Journal,* vol. 174, no. 4, p. 17.

Corbin, JM, & Strauss, A. 1990, *Grounded theory research: Procedures, canons, and evaluative criteria.* ,

Crossman, M, Segura-Dominguez, S & Allsop, W 2003, 'Low cost rock structures for beach control and coast protection: Practical design guidance', *Defra report FD2409 ISBN: 0-85521-034-6*

Cummings, P, Gordon, A, Lord, D, Mariani, A, Nielsen, L, Panayotou, K, Rogers, M & Tomlinson, R 2012, *Climate Change Adaptation Guidelines in Coastal Management and Planning*, National Committee on Coastal and Ocean Engineering, Engineers Australia, Engineering House, 11 National Circuit, Barton ACT 2600, Engineers Media, PO Box 588, Crows Nest NSW 1585, Australia.

Danielsen, F, Sørensen, MK, Olwig, MF, Selvam, V, Parish, F, Burgess, ND, Hiraishi, T, Karunagaran, VM, Rasmussen, MS & Hansen, LB 2005, 'The Asian tsunami: a protective role for coastal vegetation', *Science(Washington),* vol. 310, no. 5748, p. 643.

Davis, GA, Hanslow, DJ, Hibbert, K & Nielsen, P 1992, 'Gravity drainage: A new method of beach stabilisation through drainage of the watertable', *Coastal Engineering Proceedings,* vol. 1, no. 23

De Jong, R 1996, 'Wave transmissions at low-crested structures. Stability of tetrapods at front, crest and rear of a low-crested breakwater'

Dean, RG & Dalrymple, RA 2004, *Coastal Processes with Engineering Applications*, Cambridge University Press, Press Syndicate, University of Cambridge, The Pitt Building, Trumpington Street, UK.

Defra 2006, 'Shoreline Management Plan Guidance Volume 1: Aims and Requirements'. Department for Environment, Food and Rural Affairs London.

Dias, JA, Ferreira, Ó, Matias, A, Vila-Concejo, A & Sá-Pires, C 2003, 'Evaluation of Soft Protection Techniques in Barrier Islands by Monitoring Programs: CaseStudies from Ria Formosa (Algarve-Portugal)', *Proceedings of the Brazilian Symposium on Sandy Beaches: Morphodynamics, Ecology, Uses, Hazards and Management,* vol. 35, no. 6/5/2013, p. 14.

Dinshaw, A, Fisher, S, McGray, H, Rai, N & Schaar, J 2014b, *Monitoring and Evaluation of Climate Change Adaptation: Methodological Approaches*, Organisation for Economic Co-operation and Development, OECD Publishing

Dollard, B 1998, 'Environmentally friendly coastal protection The ECOPRO project', *Coastal Engineering Proceedings,* vol. 1, no. 26

Dupray, S, Knights, J, Robertshaw, G, Simm, J, Wimpenny, D & Ballard, BW 2010, 'The use of concrete in maritime engineering - a guide to good practice', p. 413.

ECOCARE 2015, 'Press Release - Re: Amendments proposed to the Maldivian Tourism Act – 2/99'.

Edenhofer, O, Pichs-Madruga, R, Sokona, Y, Farahani, E, Kadner, S, Seyboth, K, Adler, A, Baum, I, Brunner, S & Eickemeier, B 2014, 'Climate Change 2014: Mitigation of Climate Change: Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change'. Cambridge University Press, Cambridge UK and New York NY USA. http://mitigation2014. org.

Engelen, G, White, R, Uljee, I & Drazan, P 1995, 'Using cellular automata for integrated modelling of socio-environmental systems', *Environmental monitoring and Assessment,* vol. 34, no. 2, pp. 203-214.

EPA 2014, 'Direct Communication with EPA', ed. R-a Naeem. Environmental Protection Agency, The Republic of Maldives, Tuesday, April 22, 2014.

ERG, I 2013, *What Will Adaptation Cost? An Economic Framework for Coastal Community Infrastructure*, NOAA, Eastern Research Group, Inc

Escarameia, M 1998, *River and channel revetments: A design manual*, Thomas Telford.

Etemad-Shahidi, A & Bonakdar, L 2009, 'Design of rubble-mound breakwaters using M5 ʹ machine learning method', *Applied Ocean Research,* vol. 31, no. 3, pp. 197-201.

Fletcher, C, Taylor, B, Rambaldi, A, Harman, B, Heyenga, S, Ganegodage, K, Lipkin, F & McAllister, R 2013, 'Costs and coasts: an empirical assessment of physical and institutional climate adaptation pathways', *National Climate Change Adaptation Research Facility, Gold Coast*, p. 59.

Forbes, DL, G.S, P, G.K, M & L.A, K 2004, 'Storms and shoreline retreat in the southern Gulf of St. Lawrence', *Marine Geology* vol. 210, no. 1-4, pp. 169-204.

Freeman, GE & Fischenich, JC 2000, *Gabions for streambank erosion control*, DTIC Document

French, PW 2001, *Coastal defences: processes, problems and solutions*, Routledge, New York.

Gier, F, Schüttrumpf, H, Mönnich, J, Van Der Meer, J, Kudella, M & Rubin, H 2012, 'Stability of interlocked pattern placed block revetments', *Coastal Engineering Proceedings,* vol. 1, no. 33, p. 46.

Gilbert, J & Vellinga, P 1990, 'Strategies for adaption to sea level rise', *Report of the coastal zone management subgroup, intergovernmental panel on climate change, world meteorological organization and UN environmental programme, The Netherlands*

Glaser, B & Strauss, A 1967, 'The discovery of grounded theory. 1967', *Weidenfield & Nicolson, London*, pp. 1-19.

Gornitz, V, Couch, S & Hartig, EK 2001, 'Impacts of sea level rise in the New York City metropolitan area', *Global and Planetary Change,* vol. 32, no. 1, pp. 61-88.

Gustavson, K, Huber, RM & Ruitenbeek, HJ 2000, *Integrated coastal zone management of coral reefs: decision support modeling. Map*, World Bank-free PDF.

Gutierrez, BT, Plant, NG & Thieler, ER 2011, 'A Bayesian network to predict coastal vulnerability to sea level rise', *Journal of Geophysical Research: Earth Surface,* vol. 116, no. F2

Hancock, B, Ockleford, E & Windridge, K 2007, *An introduction to qualitative research*, NIHR RDS EM/YH.

Haq, BU 1997, *Coastal zone management imperative for maritime developing nations*, Springer.

Hasan, MS, Ebrahim, Z, Mahmood, WHW & Ab Rahman, MN 2017, 'Decision support system classification and its application in manufacturing sector: A review', *Jurnal Teknologi,* vol. 79, no. 1, pp. 153-163.

Hayen, RL 2006, 'Investigating Decision Support Systems Frameworks', p. 5.

Henson, R 2006, *The rough guide to climate change: The Symptoms, the Science, the Solutions*, Rough Guides Limited.

Hesse, S 2017, *TETRAPODS - Don't Just Love 'Em*, viewed 25 July, https://www.japantimes.co.jp/life/2007/07/22/general/tetrapods/#.Wwytf-6FOUk

Hogarth, AN & McGlade, J 1998, 'SimCoastTM: Integrating information about the coastal zone', *Echos of Expo,* vol. 98, p. 11.

Holloway, I 1997, *Basic concepts for qualitative research*, Wiley-Blackwell.

Holsapple, CW, Whinston, AB, Benamati, JH & Kearns, GS 1996, *Instructor's manual with test bank to accompany decision support systems: a knowledge-based approach*, West Publishing.

Huber, R & Jameson, S 1998, 'CORAL: A least cost management decision support model for coral reef ecosystems', *Intercoast Network,* vol. 32

Hudson, RY 1959, 'Laboratory investigation of rubble-mound breakwaters', *Reprint of the original paper as published in the Journal of the Waterways and Harbors Division of ASCE, proceedings paper 2171*

Hutchinson, S, Young, M & Macleod, A 2011, 'Caisson breakwater design for sliding', *Coastal Engineering Proceedings,* vol. 1, no. 32, p. 48.

IPCC 2014, *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, 9291691437.

Iyalomhe, F, Gallina, V, Rizzi, J, Critto, A, Marcomini, A & Torresan, S 2013, 'Inventory of GIS-Based Decision Support Systems Addressing Climate Change Impacts on Coastal Waters and Related Inland Watersheds'

J. Dronkers, J. T. E. Gilbert, L.W. Butler, J.J. Carey, J. Campbell, E. James , C. McKenzie, R. Misdorp, N. Quin, K.L. Ries, P.C. Schroder, J.R. Spradley, J.G. Titus, L. Vallianos & Dadelszen, Jv 1990, 'Strategies for Adaptation to Sea level Rise. Report of the IPCC Coastal Zone Management Subgroup: Intergovernmental Panel on Climate Change'. Intergovernmental Panel on Climate Change, Geneva, p. 148.

J.S. Reedijk, M. Muttray & H. Bergmann 2009, 'Risk Awareness – Key to a Sustainable Design Approach for Breakwater Armouring ', *Coasts, marine structures and breakwaters - Adapting to change*, 2010 edn, ed. W Allsop, Thomastelford, Edinburgh p. 12

Jachowski, RA 1965, 'Interlocking precast concrete block seawall', in *Coastal Engineering 1964*, pp. 504-517.

Jana, A & Bhattacharya, AK 2013, 'Assessment of coastal erosion vulnerability around Midnapur-Balasore Coast, Eastern India using integrated remote sensing and GIS techniques', *Journal of the Indian Society of Remote Sensing,* vol. 41, no. 3

Jennings, GR 2005, '9 Interviewing: Techniques', *Tourism research methods*, p. 99.

Kainuma, M, Nakamori, Y & Morita, T 1991, 'Development of an intelligent decision support system for environmental modeling and planning', *Research Report from the National Institute for Environmental Studies, Japan,* vol. 188, pp. 306-332.

Kamphuis, JW 2010, *Introduction to coastal engineering and management*, World Scientific Publishing Co Inc.

Kench, P 2010, *Coastal Monitoring, Reef Island Shoreline Dynamics and Management Implications,* Environment Protection Agency, Ministry of Housing, Transport and Environment

Kench, P 2012a, 'Compromising Reef Island Shoreline Dynamics: Legacies of the Engineering Paradigm in the Maldives', viewed.

Kench, P 2012b, 'Compromising Reef Island Shoreline Dynamics: Legacies of the Engineering Paradigm in the Maldives'. Springer Science.

Kim, H-J, Jamin, J, Won, M-S, Sung, H-J & Lee, J-B 2013, 'A study on the behaviour of dredged soil stratified in a transparent geobag', *The 2013 World Congress on Advances in Structural Engineering and Mechanics (ASEM13), jeju, Korea*, pp. 2980-2987

Klein, RJ, Nicholls, RJ, Ragoonaden, S, Capobianco, M, Aston, J & Buckley, EN 2001, 'Technological options for adaptation to climate change in coastal zones', *Journal of Coastal Research*, pp. 531-543.

Klingeman, PC, Kehe, SM & Owusu, YA 1984, 'Streambank erosion protection and channel scour manipulation using rockfill dikes and gabions'

Komar, PD 1983, 'Coastal erosion in response to the construction of jetties and breakwaters', *Handbook of coastal processes and erosion*, pp. 191-204.

Korkut, R, Martinez, EJ, Morales, R, Ettema, R & Barkdoll, B 2007, 'Geobag performance as scour countermeasure for bridge abutments', *Journal of Hydraulic Engineering,* vol. 133, no. 4, pp. 431-439.

Koster, MJ & Hillen, R 1995, 'Combat Erosion By Law Coastal Defence Policy for the Netherlands', *Journal of Coastal Research,* vol. 11, no. 4, pp. 1221-1228.

Koutrakis, ET, Sapounidis, A, Marzetti, S, Giuliani, V, Martino, S, Fabiano, M, Marin, V, Paoli, C, Roccatagliata, E & Salmona, P 2010, 'Public Stakeholders' Perception of ICZM and Coastal Erosion in the Mediterranean', *Coastal Management,* vol. 38, no. 4, pp. 354-377.

Kouwen, FV, Dieperink, C, Schot, P & Wassen, M 2008, 'Applicability of Decision Support Systems for Integrated Coastal Zone Management', *Coastal Management,* vol. 36, pp. 19-34.

Le Blanc, LA 1991, 'An assessment of DSS performance: the impact of utilization and closure', *Information & Management,* vol. 20, no. 2, pp. 137-148.

Leafe, R, Pethick, J & Townend, I 1998, 'Realizing the benefits of shoreline management', *Geographical Journal*, pp. 282-290.

Luisetti, T, Turner, RK, Bateman, IJ, Morse-Jones, S, Adams, C & Fonseca, L 2011, 'Coastal and marine ecosystem services valuation for policy and management: Managed realignment case studies in England', *Ocean & Coastal Management,* vol. 54, no. 3, pp. 212-224.

Mai, S & von Leiberman, N 2002, 'A decision support system for an optimal design of sea dikes with respect to risk', *Conference HydroInformatics*

Mani, J & Jayakumar, S 1995, 'Wave transmission by suspended pipe breakwater', *Journal of waterway, port, coastal, and ocean engineering,* vol. 121, no. 6, pp. 335-338.

Martin, PY & Turner, BA 1986, 'Grounded theory and organizational research', *The journal of applied behavioral science,* vol. 22, no. 2, pp. 141-157.

Mason, J 2002, *Qualitative researching*, Sage.

McCue, J, Tissier, Ml & Hills, J 2012, 'Report 6: First Draft of Guidelines Content', in *Formulation of Guidelines for Climate Risk Resilient Coastal Protection in the Maldives,* ed. CTL Consultant Ltd. Ministry of Environment and Energy (MEE), Republic of Maldives, p. 157, 23.12.2012, Guideline.

Mcglashan, DJ & Williams, E 2003, 'Stakeholder involvement in coastal decision-making processes', *Local Environment,* vol. 8, no. 1, pp. 85-94.

MEE 2011, *State of the Environment 2011*, Ministry of Environment and Energy, , Republic of Maldives, SOE4.

MEE 2013a, *Detailed island Risk and Vulnerability Assessment GDh. Thinadhoo*, Ministry of Envinronment and Energy, Republic of Maldives

MEE 2013b, *Detailed island Risk and Vulnerability Assessment HDh. Kulhudhuffushi*, Minsitry of Environment and Energy, republic of Maldives

MEE 2014, 'Direct Communication with the Ministry', eds. Najfa Shaheem Razi & Ibrahim Naufal. Ministry of Environment, Energy and Water, The Republic of Maldives

MEE 2015, 'Maldives Climate Change Policy Framework', ed. CC Department. Ministry of Environment and Energy, Maldives, p. 43.

MEE 2016, 'Second National Communication of Maldives to the United Nations Framework Convention on CLimate Change', Ministry of Environment and Energy.

MEEW 2006, 'National Adaptation Program of Action', ed. EaW Ministry of Environment, The Republic of Maldives, p. 114.

MHE 2001, 'First National Communication of Maldives to the UNFCCC'. Ministry of Hom eAffairs, Housing and Environment, Male', Maldives.

MHE 2010, *National Economic Environmnet Development Studies*, United Nations Framework Convention on Climate Change (UNFCCC) & Ministry of Housing and Environment, Republic of Maldives

MHE 2011a, *Environmental and Social Due Diligence of : Wetland Conservation and Coral Reef Monitoring Project* Ministry of Housing and Environment, Maldives

MHE 2011b, 'Survey of Climate Change Adaptation Measures in Maldives', vol. 2. Ministry of Housing and Environment, Male', Maldives, p. 128.

MHI 2014, 'Direct Communication with the Ministry', eds. Shaana Faarioog, Bareea, Evan & Labeedh. Ministry of Housing and Infrastructure, Republic of Maldives.

Mimura, N & Nunn, PD 1998, 'Trends of beach erosion and shoreline protection in rural Fiji', *Journal of coastal research*, pp. 37-46.

Mokrech, M, Hanson, S, Nicholls, RJ, Wolf, J, Walkden, M, Fontaine, CM, Nicholson-Cole, S, Jude, SR, Leake, J & Stansby, P 2011, 'The Tyndall coastal simulator', *Journal of Coastal Conservation,* vol. 15, no. 3, pp. 325-335.

Mori, N, Cox, DT, Yasuda, T & Mase, H 2013, 'Overview of the 2011 Tohoku earthquake tsunami damage and its relation to coastal protection along the Sanriku Coast', *Earthquake Spectra,* vol. 29, no. s1, pp. S127-S143.

Morimoto, Y 2001, *The Project for the Seawall Construction in Male' Island (Phase II)*, Japan International Cooperation Agency

MTCC 2014, 'Direct Communication with MTCC', eds. Ahmed Iyaz, Musthafa Moosa, Hamdhaan Baagir, Ali Shareef, Rinaz Abdulla, MK Ahmed Latheef & Yaseen Rafeeu. Maldives Transport and Contracting Company Plc.

Mujabar, PS & Chandrasekar, N 2013, 'Coastal erosion hazard and vulnerability assessment for southern coastal Tamil Nadu of India by using remote sensing and GIS', *Natural Hazards,* vol. 69, no. 3, pp. 1295-1314.

Narayana Pillai, N & Verma, D 1977, 'Shore protection using stones enclosed in nets', *Coastal Engineering,* vol. 1, pp. 349-358.

Navy 1991, *Seawalls, Bulkheads and Quaywall*, Department of Defense.

NBS 2014, 'Population and housing census 2014'. National bureau of statistics, Ministry of Finance and Treasury, Male', Maldives, National bureau of statistics, p. 107.

Neelamani, S & Sandhya, N 2005, 'Surface roughness effect of vertical and sloped seawalls in incident random wave fields', *Ocean engineering,* vol. 32, no. 3, pp. 395-416.

Neelamani, S & Vedagiri, M 2002, 'Wave interaction with partially immersed twin vertical barriers', *Ocean engineering,* vol. 29, no. 2, pp. 215-238.

Nicholls, R, Hanson, S, Mokrech, M, Stansby, P, Chini, N, Walkden, M, Dawson, R, Roche, N, Hall, J & Nicholson-Cole, S 2009, 'The Tyndall coastal simulator and interface', in *Coastal Engineering 2008: (In 5 Volumes)*, World Scientific, pp. 4341-4353.

Nicholls, RJ & Cazenave, A 2010, 'Sea-level rise and its impact on coastal zones', *science,* vol. 328, no. 5985, pp. 1517-1520.

Nicholls, RJ, Cooper, NJ & Townend, IH 2007a, '23 The management of coastal flooding and erosion', *Future flooding and coastal erosion risks*, p. 392.

Nicholls, RJ & Misdorp, R 1993, *Synthesis of vulnerability analysis studies*, Ministry of Transport, Public Works and Water Management.

Nicholls, RJ, Wong, PP, Burkett, V, Codignotto, J, Hay, J, McLean, R, Ragoonaden, S & Woodroffe, CD 2007b, 'Coastal systems and low-lying areas', in ML Parry, OF Canziani, JP Palutikof, PJVd Linden & CE Hanson (eds), *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge, UK, 315-356., Cambridge University Press, viewed.

Nicholls, RJ, Wong, PP, Burkett, V, Codignotto, J, Hay, J, McLean, R, Ragoonaden, S & Woodroffe, CD 2007c, 'Coastal systems and low-lying areas', in *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, eds. ML Parry, OF Canziani, JP Palutikof, PJVd Linden & CE Hanson. Cambridge, UK, 315-356., Cambridge University Press.

Niyaz, A & Storey, D 2011, 'Environmental management in the absence of participation: a case study of the Maldives', *Impact Assessment and Project Appraisal,* vol. 29, no. 1, pp. 69-77.

NOAA 2007, *Introduction to Stakeholder Participation* National Oceanic and Atmospheric Administration, 2234 South Hobson Avenue, Charleston, SC 29405-2413

NOAA 2013, *What Will Adaptation Cost? An Economic Framework for Coastal Community Infrastructure*, NOAA, National Oceanic and Atmospheric Administration, Coastal Services Center

Nordstrom, KF 2014, 'Living with shore protection structures: a review', *Estuarine, Coastal and Shelf Science,* vol. 150, pp. 11-23.

O'Neill Jr, CR 2000, *Structural methods for controlling coastal erosion*, Cornell Cooperative Extention, SUNY College, Brockport, NY 14420

Oberhagemann, K, Stevens, M, Haque, S & Faisal, M 2006, 'Geobags for Riverbank Protection', *ICSE-3rd International Conference on Scour and Erosion*, pp. 1-3

OECD 1991, *Climate change - Evaluating the socio-economic impacts.* , OECD, Paris, Organisation for economic co-operation and development

Oh, YI & Shin, EC 2006, 'Using submerged geotextile tubes in the protection of the E. Korean shore', *Coastal engineering,* vol. 53, no. 11, pp. 879-895.

Ozan, AY, Cihan, K & Yüksel, Y 2012, 'Propeller induced scour around the pile type berth structures', *Applied Ocean Research,* vol. 38, no. 0, pp. 16-22.

Özölçer, İH, Kömürcü, Mİ, Birben, AR, Yüksek, Ö & Karasu, S 2006, 'Effects of T-shape groin parameters on beach accretion', *Ocean engineering,* vol. 33, no. 3, pp. 382-403.

Pacheco, A, Carrasco, A, Vila-Concejo, A, Ferreira, O & Dias, J 2007, 'A coastal management program for channels located in backbarrier systems', *Ocean & coastal management,* vol. 50, no. 1, pp. 119-143.

Park, SK, Dodaran, AA, Han, CS & Shahmirzadi, MEM 2014, 'Effects of vertical wall and tetrapod weights on wave overtopping in rubble mound breakwaters under irregular wave conditions', *International Journal of Naval Architecture and Ocean Engineering,* vol. 6, no. 4, pp. 947-964.

Parker, M, Thompson, JG, Reynolds, RR & Smith, MD 1995, 'USE AND MISUSE OF COMPLEX MODELS: EXAMPLES FROM WATER DEMAND MANAGEMENT1', *JAWRA Journal of the American Water Resources Association,* vol. 31, no. 2, pp. 257-263.

Payne, PR 1980, 'Beach prisms—A shore erosion protection system embodying an artificial beach stabilizer', *Ocean Engineering,* vol. 7, no. 2, pp. 327-345.

PIANC, PIW 2003, 'Breakwaters with Vertical and Inclined Concrete Walls, Report of Working Group 28 of the Maritime Navigation Commission', *International Navigation Association*

Pilarczyk, K 1998, *Dikes and revetments: design, maintenance and safety assessment*, CRC Press.

Pilarczyk, K 2017, 'Alternatives for coastal protection', *Tạp chí Khoa học kỹ thuật Thủy lợi và Môi trường*, no. 23, p. 181.

Pilarczyk, KW 1990, *Coastal protection*, AA Balkema Rotterdam.

Pilarczyk, KW 2003, 'ALTERNATIVE SYSTEMS FOR COASTAL PROTECTION - AN OVERVIEW', in *International Conference on Estuaries and Coasts*, Hangzhou, China, p. 11, November 9-11, Online PDF Document.

Pope, J 1997, 'Responding to coastal erosion and flooding damages', *Journal of Coastal Research,* vol. 13, no. 3, pp. 704-710.

Power, DJ 2004, 'Specifying An Expanded Framework for Classifying and DescribingDecision Support Systems', *The Communications of the Association for Information Systems,* vol. 13, no. 1, p. 52.

Power, DJ 2013, *Decision Support Analytics and Business Intelligence*, Business Expert Press.

Prasetya, G 2006, 'Protection from Coastal Erosion', *Proceedings of the Regional Technical Workshop, Khao Lak, Thailand*, pp. 28-31

Ramón, G-S, Grassa, JM & Grau, JI 2009, 'Breakwater development in Spain. The last ten years', *Coasts, marine structures and breakwaters - Adapting to change,* ed. W Allsop, Thomastelford, Edinburgh, p. 18

Raudkivi, AJ & Dette, H-H 2002, 'Reduction of sand demand for shore protection', *Coastal engineering,* vol. 45, no. 3, pp. 239-259.

Regelgeving, CCURe 2005, *Handbook Quay Walls*, Taylor & Francis.

Research, CI, Association, I, Regelgeving, CCURe & fluviales, Cdéme 2007, *The Rock Manual: The use of rock in hydraulic engineering*, Ciria.

Rijsberman, F & Westmacott, S 2000, 'Costeffectiveness analysis of coral reef management and protection: A case study of Curacao', *Integrated coastal zone management of coral reefs: Decision support modeling. The International Bank for Reconstruction and Development, The World Bank, Washington DC, USA*, pp. 49-66.

Roberts, TM & Wang, P 2012, 'Four-year performance and associated controlling factors of several beach nourishment projects along three adjacent barrier islands, west-central Florida, USA', *Coastal Engineering,* vol. 70, pp. 21-39.

Robertshaw, G, Cunningham, L & pomfret, M 2012, 'Blackpool central area coast protection scheme, UK', *Proceedings of the Institution of Civil Engineers-Maritime Engineering*, Thomas Telford Ltd.

Rozum, JS & Carr, SD 2013, 'Tools for Coastal Climate Adaptation Planning: A guide for selecting tools to assist with ecosystem-based climate planning.', p. 48.

Salman, A, Lombardo, S & Doody, P 2004, *Living with coastal erosion in Europe: Sediment and Space for Sustainability - A guide to coastal erosion management practices in Europe*, EUCC

Sawaguchi, M 1974, 'Lateral behavior of a double sheet pile wall structure', *Soils and foundations,* vol. 14, no. 1, pp. 45-59.

Schirmer, M, Schuchardt, B, Hahn, B, Bakkenist, S & Kraft, D 2003, 'KRIM: Climate change risk construct and coastal defence', *DEKLM German climate research programme. Proceedings*, pp. 269-273.

Schmidt, L, Delicado, A, Gomes, C, Granjo, P, Guerreiro, S, Horta, A, Mourato, J, Prista, P, Saraiva, T & Truninger, M 2013, 'Change in the way we live and plan the coast: stakeholders discussions on future scenarios and adaptation strategies', *Proceedings 12th International Coastal Symposium (Plymouth, England). J. Coast. Res*, pp. 1033-1038

Scott, H, McEvoy, D, Chhetri, P, Basic, F & Mullett, J 2013, *Climate change adaptation guidelines for ports*, Enhancing the resilience of seaports to a changing climate report series. Gold Coast, Australia: National Climate Change Adaptation Research Facility. http://www. nccarf. edu. au/sites/default/files/attached_files_publications/Scott_2013_Climate _change_adaptation_guidelines_for_ports_Final. pdf.

Scottish Natural Heritage 2017, *A guide to managing coastal erosion in beach/dune systems*, viewed 31 August, <http://www.snh.org.uk/publications/on-line/heritagemanagement/erosion/appendix_1.16.shtml.>.

Smith, MD, Slott, JM, McNamara, D & Murray, AB 2009, 'Beach nourishment as a dynamic capital accumulation problem', *Journal of Environmental Economics and Management,* vol. 58, no. 1, pp. 58-71.

Sorensen, R 1991, 'Impact of Expected Climate Change Effects on Coastal Structure Design', *Proceedings, Coastal Structures and BreakWvaters Conference*, pp. 1-12

Sorensen, RM 2005, *Basic coastal engineering*, Springer Science & Business Media.

Sorensen, RM, Weisman, RN & Lennon, GP 1984, 'Control of erosion, inundation, and salinity intrusion caused by sea level rise', *Barth MC, Titus JG (eds) Greenhouse effect and sea level rise. A challenge for this generation. Van Nostran Reinhold Company Inc, New York. Pp179,* vol. 214

SPM 1984, 'Shore protection manual', *Department of the Army, Waterways Experiment Station, Vicksburg, Mississippi*

Starks, H & Brown Trinidad, S 2007, 'Choose your method: A comparison of phenomenology, discourse analysis, and grounded theory', *Qualitative health research,* vol. 17, no. 10, pp. 1372-1380.

Stive, MJF, Nicholls, RJ & Vriend, HJd 1991 'Sea-level rise and shore nourishment: a discussion', *Coastal Engineering,* vol. 16, no. 1, pp. 147-163.

Strauss, A & Corbin, J 1994, 'Grounded theory methodology', *Handbook of qualitative research,* vol. 17, pp. 273-285.

Sujanapal, P & Sankaran, K 2016, 'Common Plants of Maldives', *Bangkok: Food and Agriculture Organization of the United Nations and Kerala Forest Research Institute*

Sundar, V & Subbarao, B 2003, 'Hydrodynamic performance characteristics of quadrant front-face pile-supported breakwater', *Journal of waterway, port, coastal, and ocean engineering,* vol. 129, no. 1, pp. 22-33.

Swan River Trust 2009, *Best management practices for foreshore stabilisation - Approcahes and decision support framework*, State Government of Western Australia

Te'eni, D & Ginzberg, MJ 1991, 'Human-computer decision systems: the multiple roles of DSS', *European journal of operational research,* vol. 50, no. 2, pp. 127-139.

Terzaghi, K 1954, *Anchored bulkheads*, Wiley Online Library.

Thieler, ER & Hammar-Klose, ES 1999, *National assessment of coastal vulnerability to sea-level rise; US Atlantic Coast*, 2331-1258.

Thomas, R & Hall, B 2015, *Seawall design*, Butterworth-Heinemann.

Thorn, RB 1960, *The design of sea defence works*, Butterworths Scientific Publications, London.

Thorn, RB & Roberts, AG 1981a, *Sea defence and coast protection works: a guide to design*, Telford.

Thorn, RB & Roberts, AG 1981b, *Sea Defence and Coast Protection Works: Guide to Design*, Thomas Telford Ltd.

Thorne, CR, Abt, SR & barends, FBJ 1995, *River, Coastal and Shoreline Protection*, John Wiley & Sons Ltd, United Kingdom.

Torresan, S, Critto, A, Rizzi, J, Zabeo, A, Furlan, E & Marcomini, A 2016, 'DESYCO: a decision support system for the regional risk assessment of climate change impacts in coastal zones', *Ocean & Coastal Management,* vol. 120, pp. 49-63.

Turner, BA 1981, 'Some practical aspects of qualitative data analysis: one way of organising the cognitive processes associated with the generation of grounded theory', *Quality & Quantity,* vol. 15, no. 3, pp. 225-247.

UNDP 2006, *Developing a Disaster Risk Profile for Maldives*, United Nations Development Programme, Maldives

UNDP 2007, *Detailed Island Risk Assessment in Maldives*, United Nations Development Programme, UNDP Maldives

UNDP 2010, 'Present cost-effective, locally appropriate coastal management and drainage management options contributing to climate change resilience of communities in Fares-Maathoda', United Nations Development programme, p. 17, 8/1/2015, Project Document.

UNDP 2013, 'CBA Country Programme Strategy Maldives', p. 18.

UNEP-GPA, *The Cairo Principles - Guiding principles for post-tsunami rehabilitation and reconstruction*, viewed 29/11/2016, <http://www.gdrc.org/oceans/tsunami_coastal-guidelines.html.>.

UNFCCC 2013, *Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change*, viewed 22 August

<http://unfccc.int/files/adaptation/methodologies_for/vulnerability_and_adaptation/application/pdf/decision_support_models_cosmo.pdf

USACE 1981a, 'Low-cost shore protection. Final report on the shoreline erosion control demonstration program (section 54)', *Wash-ington, DC: Office of the Chief of Engineers*

USACE 1981b, 'Low Cost Shore Protection - a guide for local government officials', p. 103.

USACE 1981c, 'Low Cost Shore Protection, a Guide for Engineers & Contractors', *US Army Corps of Engineers*, pp. 1-173.

USACE 1984, *Shore protection manual* United States Army Corps of Engineers Coastal Engineering Research Center

USACE 1995, 'Design of Coastal Revetments, Seawalls, and Bulkheads'

USACE 2002, 'Coastal engineering manual', *Engineer Manual,* vol. 1110, pp. 2-1100.

USACE 2003, 'Army Corps of Engineers 2003', *Coastal Engineering Manual, Part. V. Coastal and Hydraulics Lab., US Army Engineer Research and Development Center, Vicksburg, Mississippi, USA*

USAID 2012, 'Climate Vulnerability Assessment - Islands of Dhiddhoo and Hinnavaru, the Maldives'. US Agency for International Development, p. 60.

Usha, R & Gayathri, T 2005, 'Wave motion over a twin-plate breakwater', *Ocean engineering,* vol. 32, no. 8, pp. 1054-1072.

van de Graaff, J, Niemeyer, HD & van Overeem, J 1991, 'Beach nourishment, philosophy and coastal protection policy', *Coastal engineering,* vol. 16, no. 1, pp. 3-22.

Van der Meer, J 1999, 'Design of concrete armour layers', *Proceedings of the Coastal Structures*, pp. 213-221

Van Der Meer, JW 1988, 'Rock slopes and gravel beaches under wave attack'

van der Meer, JW, Briganti, R, Zanuttigh, B & Wang, B 2005, 'Wave transmission and reflection at low-crested structures: Design formulae, oblique wave attack and spectral change', *Coastal Engineering,* vol. 52, no. 10, pp. 915-929.

Van Gent, M, Plate, S, Berendsen, E, Spaan, G, Van Der Meer, J & d'Angremond, K 1999, 'Single-layer rubble mound breakwaters', *Proc. Coastal Structures*

Venton, CC, Venton, P & Shaig, A 2009, *Cost Benefit Study of Disaster Risk Mitigation Measures in Three Islands in the Maldives*, UNDP, DHTE Maldives, Republic of Maldives

Vermaat, J & Thampanya, U 2006, 'Mangroves mitigate tsunami damage: A further response', *Estuarine, Coastal and Shelf Science,* vol. 69, no. 1-2, pp. 1-3.

Wadey, M, Brown, S, Nicholls, RJ & Haigh, I 2017, 'Coastal flooding in the Maldives: an assessment of historic events and their implications', *Natural Hazards,* vol. 89, no. 1, pp. 131-159.

Warrick, R 2009, 'Using SimCLIM for modelling the impacts of climate extremes in a changing climate: a preliminary case study of household water harvesting in Southeast Queensland. 18th World IMACS', *MODSIM Congress, Cairns, Australia*, Citeseer, pp. 2583-2589

Watanuki, A & Yamamoto, A 1990, 'Settlement of seaweeds on coastal structures', *Hydrobiologia,* vol. 204, no. 1, pp. 275-280.

Weggel, JR 1988, 'Seawalls: The need for research, dimensional considerations and a suggested classification', *Journal of Coastal Research*, pp. 29-39.

Westmacott, S 2001, 'Developing decision support systems for integrated coastal management in the tropics: Is the ICMdecision-making environment too complex for the development of a useable and useful DSS?', *Journal of Environmental Management,* vol. 62, p. 20.

Westmacott, S & Rijsberman, F 1995, 'CORAL, coastal management model for the sustainable development of coral reef areas', *Physics and Chemistry of the Earth,* vol. 20, no. 3, pp. 245-250.

White, R, Engelen, G & Uljee, I 2000, 'Modelling land use change with linked cellular automata and socio-economic models: A tool for exploring the impact of climate change on the island of st lucia', *Spatial information for land use management*, p. 189.

Williams, A & Katz, L 2001, 'The use of focus group methodology in education: Some theoretical and practical considerations, 5 (3)', *IEJLL: International Electronic Journal for Leadership in Learning,* vol. 5

WorldBank 2005, *Update on the World Bank response to the Tsunami Disaster*, World Bank

Wratt, D, Mullan, B, Salinger, J, Allan, S, Morgan, T & Kenny, G 2004, 'Coastal Hazards and Climate Change. A guidance manual for Local Government in New Zealand'

WRC 2011, *Community Perception of Coastal Processes and Management Options for Coastal Erosion*, Waikato Regional Council, Hamilton East

WRL 2013, *Assessment and Decision Frameworks for Seawall Structures*, Sydney Coastal Councils Group

Young, I 1999, 'Seasonal variability of the global ocean wind and wave climate', *International Journal of Climatology,* vol. 19, no. 9, pp. 931-950.

Zanuttigh, B, Simcic, D, Bagli, S, Bozzeda, F, Pietrantoni, L, Zagonari, F, Hoggart, S & Nicholls, RJ 2014, 'THESEUS decision support system for coastal risk management', *Coastal Engineering,* vol. 87, pp. 218-239.

11 APPENDICES

APPENDIX A – ETHICAL APPROVAL, INFORMATION TO PARTICIPANTS, AND CONSENT FORM

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

HUMAN ETHICS COMMITTEE

Secretary, Lynda Griffioen
Email: human-ethics@canterbury.ac.nz

Ref: HEC 2014/06

26 March 2014

Abdulla Abdul Hakeem
Department of Civil & Natural Resources Engineering
UNIVERSITY OF CANTERBURY

Dear Abdulla

The Human Ethics Committee advises that your research proposal "Designing a decision support framework for selecting appropriate coastline protection systems in the Maldives" has been considered and approved.

Please note that this approval is subject to the incorporation of the amendments you have provided in your email of 25 March 2014.

Best wishes for your project.

Yours sincerely

Lindsey MacDonald
Chair
University of Canterbury Human Ethics Committee

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Telephone: +64212154644

Email: abdulla.abdulhakeem@pg.canterbury.ac.nz

Designing a decision support framework for selecting appropriate coastline protection systems in the Maldives

Information Sheet

I am a PhD student at the Department of Civil and Natural Resources Engineering, University of Canterbury. I am currently conducting a research titled 'designing a decision support framework for selecting appropriate coastline protection systems in the Maldives'. This project will collect information related to coastline protection works in the Republic of Maldives from different perspectives. The participants of this study include policy makers, industry professionals, local council members and members of the general public including key stakeholders from the public.

I would like to invite you to participate in my current study. If you agree to take part you will be asked to do the following:

- Complete a questionnaire about past and present coastal protection practices in your island, and your opinion of the coastal protection practices in general. This will take approximately 30 minutes, AND/OR
- Take part in an interview / community workshop or a discussion forum related to coastline protection works. This will take approximately 60 minutes.

Please note that participation in this study is voluntary. If you do participate, you have the right to withdraw from the study at any time without penalty. If you withdraw, I will do my best to remove any information relating to you, provided this is practically achievable.

I will take particular care to ensure the confidentiality of all data gathered for this study. I will also take care to ensure your anonymity in publications of the findings. All the data will be securely stored in password protected facilities and locked storage at the University of Canterbury for ten years following the study. It will then be destroyed.

The results of this research may be used to devise a Decision Support Framework (DSF) to facilitate coastal engineers, decision makers and other relevant stakeholders in selecting the most appropriate form of coastline protection systems for the RoM from a range of available options. The results may also be reported internationally at conferences and in engineering journals.

If you have any questions about the study, please contact me (details above) and/or my supervisor, Professor Rajesh Dhakal, +6433642512 (rajesh.dhakal@canterbury.ac.nz). If you have a complaint about the study, you may contact the Chair, Educational Research Human Ethics Committee, University of Canterbury, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz).

If you agree to participate in this study, please complete the attached consent form and return it to me in the envelope provided by (Day/Month). The questionnaire will be sent to you in a closed envelope by mail or delivered in person. The package will also include a self addressed envelope in which to enclose the completed questionnaire. Completed questionnaires will be collected from you. For the workshop and interviews, you will be contacted by phone, using details provided in the consent form.

I am looking forward to working with you and thank you in advance for your contributions

Abdulla Thasleem Abdul Hakeem

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Telephone: +64212154644

Email: abdulla.abdulhakeem@pg.canterbury.ac.nz

Designing a decision support framework for selecting appropriate coastline protection systems in the Maldives

Consent Form

I have been given a full explanation of this project and have been given an opportunity to ask questions.

I understand what will be required of me if I agree to take part in the project.

I understand that my participation is voluntary and that I may withdraw at any stage without penalty.

I understand that any information or opinions I provide will be kept confidential to the researcher and that any published or reported results will not identify me.

I understand that all data collected for the study will be kept in locked and secure facilities at the University of Canterbury and will be destroyed after ten years.

I understand that I will receive a report on the findings of the study. I have provided my email or postal details below for this purpose.

I understand the risks associated with taking part and how they will be managed.

I understand that if I require further information I can contact the researcher, Abdulla Thasleem Abdul Hakeem. If I have any complaints, I can contact the Chair of the University of Canterbury Educational Research Human Ethics Committee.

By signing below, I agree to participate in this research project.

Name: --

Date: --

Signature: --

Email address: --

Please return this completed consent form to Abdulla Thasleem Abdul Hakeem, 10 Wadeley Rd, Ilam, 8041, Christchurch, Canterbury, New Zealand, in the envelope provided by (Day/Month).

APPENDIX B – LOCAL STAKEHOLDER SURVEY QUESTIONNAIRE

DESIGNING A DECISION SUPPORT FRAMEWORK (DSF) FOR SELECTING APPROPRIATE

COASTLINE PROTECTION SYSTEMS

QUESTIONNAIRE FOR LOCAL COMMUNITY

The aim of this survey is to collect information related to coastline protection projects/works in the Republic of Maldives (RoM) to devise a Decision Support Framework (DSF) to facilitate coastal engineers, decision makers and other relevant stakeholders in selecting the most appropriate form of coastline protection systems for the RoM from a range of available options. The survey is also intended to initiate a dialogue among local decision-makers and provide information on local actions to improve coastline protection works.

We would value your comments, observations, and suggestions and kindly ask you to answer the following questions.

1- Who manage sand protects the coastline of this island?

❑ Local authorities
❑ Government
❑ None of the above
❑ Other (Please specify) ____________________

2- Who do you think should protect and maintain coastline of this island?

❍ Local authorities
❍ Government
❍ Residents
❍ Beach users
❍ Other (Please specify) ____________________

3- Please check one of the boxes below

	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
Are you satisfied with the way the island's coastline is managed and protected?	❍	❍	❍	❍	❍

4- Which of the coastline protection system(s) do you know? 1 to 5 are soft approaches while the rest are hard approaches). You may refer to the photos below.

- ❑ Reclamation (1)
- ❑ Beach nourishment (2)
- ❑ Beach ridge construction (3)
- ❑ Managed re-alignment (4)
- ❑ Vegetation (5)
- ❑ Sea walls (Rock armour/Steel sheets/bags) (6)
- ❑ Breakwaters – Rock/Concrete/Steel sheet/Caission/Bags (7)
- ❑ Groynes (8)
- ❑ Gabions (9)
- ❑ Revetments (Bags/blocks) (10)
- ❑ Vegetation (11)
- ❑ Other (Please specify) ____________________

5- Which of the coastline protection system do you think is more appropriate for your this island? (Please refer coastline protection systems in Q4)

- ❑ Reclamation (1)
- ❑ Beach nourishment (2)
- ❑ Beach ridge construction (3)
- ❑ Managed re-alignment (4)
- ❑ Vegetation (5)
- ❑ Sea walls (Rock armour/Steel sheets/bags) (6)
- ❑ Breakwaters – Rock/Concrete/Steel sheet/Caission/Bags (7)
- ❑ Groynes (8)
- ❑ Gabions (9)
- ❑ Revetments (Bags/blocks) (10)
- ❑ Vegetation (11)
- ❑ Other (Please specify) ____________________

6- If you prefer any of the options in Question 4, please rank them in order of preference (number of stars circled will indicate your preference order).

******** Aesthetic reason(s)

******** Best way of defending the coastline

******** Easy for monitoring and maintenance

******** Economically more attractive

******** Durable (long lasting)

******** More suitable for boats

******** Low impacts to environmental degradation

******** Other(s). (Please specify)

7- Given the rate of current coastline erosion in this island, coastline protection to combat erosion is:

- ❍ A priority
- ❍ Important
- ❍ Not very important
- ❍ None of the above. Please provide your opinion ____________________

8- If your answer to Q7 is 'Not very important'; please specify your reason(s) for the choice.

____

____

9- Which option best describes your situation: (Please tick one option only)

- ❍ Permanent resident, own a property in this island
- ❍ Permanent resident, renting a property in this island
- ❍ Visitor, own a property in this island (e.g. if it is your Bach or holiday home)
- ❍ Visitor, do not own a property in this island
- ❍ Other (Please specify) ____________________

10- If you are a permanent resident, how long have you been residing in this island? (Tick one option only)

- ❍ Less than a year
- ❍ More than a year but less than 5 years
- ❍ More than 5 years but less than 10 years
- ❍ More than 10 years

11- If you are an immigrant, what is the reason of migration?

- ❍ Education
- ❍ Environmental reason(s)
- ❍ Economic reason(s)
- ❍ Social reason(s)
- ❍ Other (Please specify) ____________________

12- Thinking of the past couple of years, which option best describes how often you visit the beach/coast? (Tick one option only)

- ❍ Never
- ❍ Once a Year or Less
- ❍ Several Times a Year
- ❍ Once a Month
- ❍ 2-3 Times a Month
- ❍ Once a Week
- ❍ 2-3 Times a Week
- ❍ 4-6 Times a Week
- ❍ Daily

13- Next are a few things users value about their coastlines or beaches. Please indicate how important each value is to you.

	Very Important	Important	Neutral	Not important	Not at all Important
Appearance of the beach (whether or not they are natural)	❍	❍	❍	❍	❍
Good recreational facilities in general (e.g. boat ramps, reserves, etc)	❍	❍	❍	❍	❍
A dry beach at high tide levels for recreational activities, such as sun bathing and sports	❍	❍	❍	❍	❍
Easy access onto the beach	❍	❍	❍	❍	❍
Walking access along the full length of the beach at high tide	❍	❍	❍	❍	❍
Protection of traditional and local values	❍	❍	❍	❍	❍
Retaining some undeveloped, natural beaches around the coast	❍	❍	❍	❍	❍
Protection of scenic values when looking out over the beach and toward the sea	❍	❍	❍	❍	❍
Protection of scenic values when looking inland (e.g. towards houses or the surrounding landscape)	❍	❍	❍	❍	❍
The involvement of local people in decision making about the coast	❍	❍	❍	❍	❍

The involvement of people who do not live locally in decision making about the coast	❍	❍	❍	❍	❍
Protecting beachfront property, even if it means losing the sandy beach	❍	❍	❍	❍	❍
Good fishing	❍	❍	❍	❍	❍
Your suggestions on what you value about the coast (please describe)	❍	❍	❍	❍	❍

14- Which are the two main natural hazards you consider most likely to affect this island?

- ❑ Flooding
- ❑ Storm or cyclone with high winds
- ❑ Earthquake
- ❑ Tsunami
- ❑ Sea level rise

15- Have you ever (a) personally experienced any of the following hazards in the past, and/or (b) suffered loss or damage as a result? (tick all that apply)

	I've had personal experience of:	I've experienced loss/damage due to:
Flooding		
Storm or cyclone with high winds		
Earthquake		
Tsunami		
Sea level rise		

16- What is your biggest concern regarding coastal erosion in this island?

- ❍ Loss of natural environment
- ❍ Loss of sand
- ❍ Loss of benefits for local community (i.e.: Tourism will be affected)
- ❍ Loss of enjoyment for visitors
- ❍ Other (Please specify) ____________________

17- What do you think is the main cause of coastal erosion in this island?

❍ Changes in the sand supply to the beach by natural means
❍ Coral mining/blasting
❍ Sand mining
❍ Storms
❍ Sea level rise
❍ Structural changes to coastline
❍ Other (Please specify) ____________________

18- In general, who do you think should fund coastline protection measures where private property is at risk? (tick all that apply)

❑ Private owners whose properties are at risk
❑ Local community
❑ Central government
❑ Other (Please specify) ____________________

19- In general, who do you think should fund coastline protection measures where public property (e.g. reserves and roads) is at risk? (tick all that apply)

❑ Private property owners living nearby (e.g. at risk of losing road access)
❑ Local community
❑ Central government
❑ Other (Please specify) ____________________

20- Please tell us any thoughts you have on your choices for questions 18 and 19

____

____

21- Are you familiar with the type (s) of coastline protection used in this island? If the answer is 'No', please skip ahead to Q24.

❍ Yes
❍ No

22- How do you rate the success of the approaches used in the protection of this islands coastline? (tick one option only)

❍ Very high
❍ High
❍ Low
❍ Very low

23- Has your usage of the beach been affected by the current coastline structures?

- ❍ Positively affected (How?) ____________________
- ❍ Much the same as before
- ❍ Negatively affected (How?) ____________________

24- Thinking back to before the current coastline protection began, did you personally… (tick all that apply)

- ❑ Attend any public meetings about the proposed approach
- ❑ Participate in any focus groups or interviews
- ❑ Complete a survey (e.g. a questionnaire or phone survey)
- ❑ Make submissions about the proposed approach (e.g. to council)
- ❑ Receive any information about the approach (e.g. flyers, newspapers etc.). If yes, please describe __________
- ❑ Actively seek information about the approach. If yes, please describe. ____________________
- ❑ Other (Please specify) ____________________
- ❑ I was aware the approach was being proposed, but was not involved in any way
- ❑ I was not aware the approach was being proposed (if so, skip to question 31)

25- Once again, think back to before the current coastline protection programme began. Please indicate how much you agree or disagree with the following statements (tick one for each line).

	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
I expected the scheme to look different to how it looks now					
I expected the scheme to have less impact on how the coastline looks now					
I expected the scheme to have less impact on my use of the beach					
I was well aware of the impacts of the scheme					
I would have liked more opportunities to become involved in decision making before the scheme was put in place					
There was an adequate amount of information available about the proposed scheme					
I was not interested in the scheme before it was implemented					

26- Please consider each of the following statements and tick the box on each line that best describes your attitude:

	Strongly agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
I am happy with the 'package' of coastal protection measures used at this islands beach					
The current approach to managing coastal erosion benefits everyone					
Precast concrete walls are the best long-term approach to protecting properties in this island					
Sand replenishment/nourishment or reclamation is the best long-term approach to protecting beachfront properties at this island					
Precast concrete walls spoil the natural character of the islands beach					
I like the appearance of this islands beach					
I would be happy to see hard walls replaced by soft techniques at this islands Beach					
It is unfair to 'let the sea dictate' (i.e. do nothing) when people and properties are at risk					
Managed retreat - moving of buildings back from the beachfront is the best long-term approach to protecting beachfront properties in this island					

27- If you have any other comments about coastline protection works at this island, please write them here:

28- Can you remember back to how the beach looked before the current coastline protection was put in place?

- ❍ Yes (Please go to Q30)
- ❍ No (Please go to Q31)

29- If the island currently has a seawall, please think back to before the coastal protection was put in place and indicate how much you agree or disagree with the following statements (Please tick the option in each row that best matches your view).

	Strongly agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
I expected the wall to look different					
I expected the wall to have less impact on how the beach looks now					
I expected the wall to have less impact on my use of the beach					
I would have liked more opportunities to become involved in decision-making					
There was an adequate amount of information available about the proposed wall					
The concrete wall hasn't had much effect on the beach in front of it					
It was a good idea to build the concrete wall					

30- Have you participated in any decision-making processes (e.g. public meetings, making a submission) with respect to coastal protection at this islands coastline?

- ❍ Yes (Please describe) ____________________
- ❍ No

31- Are you?

- ❍ Male
- ❍ Female

32- Which best describes the situation you are living in now? (tick one option only)

- ❍ Family with children
- ❍ Family without children
- ❍ Alone
- ❍ With non-family
- ❍ Other (Please specify) ____________________

33- What is your age group?

- Under 18
- 18 to 35
- 36 to 55
- 55+

34- What is your current employment status? (tick one option only)

- Employed full-time
- Employed part-time
- Not in paid employment (e.g. if you are retired or an at-home parent)
- self employed
- Unemployed

35- What is your monthly income range?

- Under Mrf5000
- Between Mrf5000 -Mrf 15000
- Between Mrf 15000 - Mrf 30000
- Between Mrf30000 - Mrf 50000
- 50000+

36- What is your highest educational qualification?

- No school qualifications
- Secondary school
- Trade certificate or professional certificate/Diploma
- University Undergraduate degree
- University Postgraduate degree

37- Have you had any experience with environmental matters (e.g. have you been involved in activities, groups or employment related to the environment)?

- Yes (Please give details) ____________________
- No

38- Please use this space to write any other comments regarding coastal protection management in general, or this survey. All remarks will be useful

Thank you!

APPENDIX C – PROFESSIONALS' INTERVIEW QUESTIONNAIRE

DESIGNING A DECISION SUPPORT FRAMEWORK (DSF) FOR SELECTING APPROPRIATE COASTLINE PROTECTION SYSTEMS

QUESTIONNAIRE FOR PROFESSIONALS

The purpose of this questionnaire is to collect information relevant to different coastal protection measures used in the Republic of Maldives, to formulate a Decision Support Framework (DSF) for selecting appropriate coastal protection measures. The questionnaire is anonymous and all information will be treated with strict confidentiality.
We would value your comments, observations, and suggestions and kindly ask you to answer the following questions.

1- Looking at the types of coastline protection measures already applied in the islands, have any DSFs been used in selecting the most feasible options?

- ❍ Yes (please explain) ___________________________________
- ❍ No

2- In order to select most appropriate coastline protection structures for the islands, do you agree that a DSF is required for the Maldives?

- ❍ Yes
- ❍ No
- ❍ Other (please explain) ____

3- Do you or your organization use any DSFs in the coastline protection decision making? If your answer is 'yes', please list all separated by a /

- ❍ Yes ____________________
- ❍ No
- ❍ Other (please explain) ____________________

4- What do you think are the key parameters that should be addressed in a decision support framework for selecting appropriate measures for coastline protection? Please select all that apply.

- ❑ Constructability
- ❑ Financial feasibility
- ❑ Durability
- ❑ Design reliability
- ❑ Environmental sustainability
- ❑ Socio-Aesthetics acceptability
- ❑ Hazards and vulnerability
- ❑ Others (please explain) ____

5- To design a DSF for coastline protection decision making in the Maldives, what is your opinion about considering other similar DSFs from outside the country?

- ❍ DSFs designed by developed countries would be better to look at (please explain) ________________
- ❍ DSFs designed by island nations would be better to get experience from (please explain) ___________
- ❍ Both
- ❍ Not necessary to look at other DSFs

6- Are there any systems currently in place to cut down costs by considering the available DSFs for coastline protection decision making in the Maldives?

- ❍ Yes (please explain) ____
- ❍ No

7- The mandate of coastline protection and infrastructure development in the Maldives are separated and executed under different ministries/agencies. Would it cut down cost if the projects are being run under a single government institution?

- ❍ Yes (please explain) ____
- ❍ No (please explain) ____

8- Projects are mostly carried out in outer atolls/islands in the Maldives. However, all the pre-construction works including design finalization, feasibility and construction options are being decided by the policy makers in Male'. What is your opinion of increasing local stakeholder contribution in these decisions?

- ❍ It will bring in more unwanted, unresolved problems
- ❍ It will make the process better ____
- ❍ Other____

9- What is your opinion about deciding the priority of islands and the types of measures for coastline protection in those islands?

- ❍ They are politically motivated
- ❍ They are prioritised based on need
- ❍ Other (please explain) ____

10- Are cost benefit analyses or financial feasibility studies done prior to finalizing a method of coastline protection?

- ❍ Yes
- ❍ No (please explain) ____

11- Do you or your organisation use the lessons from past projects (coastline changes due to the types of coastline protection system implemented) when making decisions for future projects?

- ❑ Yes
- ❑ No (please explain) ____
- ❑ Other (please explain) ____

12- Which of the following coastline protection options do you consider to be the most appropriate solution for Maldive islands?

- ❍ a - Soft coastline protection options
- ❍ b - Hard engineered options
- ❍ Combination of both a and b
- ❍ Others (please explain) ____

13- What are the most frequently used types of coastline protection measures in the Maldives? (The first four types are soft options and the rest are hard engineered options).

- ❑ Reclamation
- ❑ Beach nourishment
- ❑ Beach Ridge Construction
- ❑ Sea walls/ Bulkheads – (Rock armour/Sheetpile/Concrete/Bags)
- ❑ Breakwaters – (Rock armour/Tetrapod/Coral mound/Sand-Cement Bags/Geobags/Caisson/Sheetpiles)
- ❑ Groynes
- ❑ Gabions
- ❑ Revetments – (Sand-cement Bags/Precast concrete blocks)
- ❑ Vegetation
- ❑ Embankments
- ❑ Others (please explain) ____

14- What in your opinion is the main reason for the decline in projects with steel sheet piling in the Maldives?

- ❍ Not compatible to Maldives environment
- ❍ Due to steel price escalation
- ❍ Due to decline in number of port projects
- ❍ Others (please explain) ____

15- Are groynes or groyne fields used in the Maldives as coastline protection measures?

- ❍ Yes
- ❍ No

16- Is managed re-alignment a practical option for the Maldives?

- ❍ Yes
- ❍ No (please explain) ____

17- Is beach ridge construction / dune restoration a viable option to combat coastal erosion in the Maldives?

- ❍ Yes
- ❍ No (please explain) ____

18- Is replenishment or beach nourishment an option for coastline protection in the Maldives?

- ❍ Yes
- ❍ No (please explain) ____

19- Can submerged breakwaters be applied in the Maldive islands as coastline protection measures?

- ❍ Yes
- ❍ No (please explain) ____

20- Off shore breakwaters (BW) are aesthetically unattractive for some people, especially tourists. What in your opinion would be the governing factor in deciding a breakwater?

- ❍ Coastline protection is the primary objective
- ❍ Tourism being the country's number one earning industry, decisions should be based on aesthetics
- ❍ Other (please explain) ____

21- Are there any local materials in the Maldives that could be used in the construction of coastline protection measures?

❍ Yes (please explain) ____

❍ No

22- Are there any material that could be used as an alternative to rock armours?

❍ Yes (please explain) ____

❍ No

23- What are the main types of sea walls and bulkheads used in the Maldives?

❑ Concrete sheet piled walls

❑ Sand-cement bag walls

❑ Precast concrete walls

❑ Steel sheet piled walls

❑ Rock armours

❑ Others (please explain) ____

24- Some researchers argue seawalls and bulkheads are not methods of coastline protection from coastal erosion. Rather, they find seawalls act more of fixing coastline while protecting nearby properties. What in your opinion are the primary role of function of seawalls/bulkheads?

- ❍ A- Fixing coastline and protecting nearby properties
- ❍ B- Protecting coastlines from coastal erosion
- ❍ A and B
- ❍ Other (please explain)____

25- What in your opinion are the main factors contributing to coastline erosion in the Maldives? Please select all that apply

- ❑ Forestation or vegetation issues
- ❑ Hydrodynamic forces - tides, winds and storms
- ❑ Bathymetric conditions o reef flat and lagoon
- ❑ Beach material
- ❑ Coastal ridge height
- ❑ Structural modifications/changes to coastline
- ❑ Changes in the sand supply
- ❑ Location, shape and orientation of island
- ❑ Others. (please explain) ____

26- Have you experienced /been aware of any cases of accelerated coastline erosion as a result of a coastal protection measure being implemented OR as a result of other structural modifications to the coastline?

- ❑ Yes - as a result of a coastal protection measure (please explain)_________________________________
- ❑ Yes - as a result of other structural modifications (please explain) ______________________
- ❑ No

27- In general, which of the following 'planning and management' approaches do you consider to be the workable long term approaches for the islands of Maldives? (Select all that apply)

- ❑ Do Nothing: Letting the sea dictate
- ❑ Managed Realignment: Leaving the coast to erode but the critical infrastructure/properties, lives and livelihoods to move inland
- ❑ Hold The Line: Building structures to control further coastline erosion
- ❑ Move Seaward: Making the beach wider towards sea
- ❑ Limited Intervention: Using natural means or regulatory changes to slow down the rate of erosion

28- Have any new safety featured being incorporated to coastline protection works after 2004 tsunami?

- ❍ Yes (please explain) ____
- ❍ No
- ❍ Other ____

29- Would it be feasible for the Maldives to tackle coastline erosion in all the 180+ inhabited islands?

- ❍ Yes (please explain) ____
- ❍ No (please explain) ____

30- Do you support population and development consolidation (PDC) program in the Maldives?

- ❍ Yes (please explain) ___________________________________
- ❍ No (please explain) ___________________________________

31- IPCC, in their last report (IPCC-AR5) estimated a global Sea Level Rise (SLR) of nearly 1m for the next 100 years. A 1m rise of SLR could inundate most of the islands in the Maldives as the average land height is 1m from MSL. Through your experience, the literature and data available to you, what is your opinion about SLR?

- ❍ SLR is a myth (please explain) ____
- ❍ SLR is a fact (please explain) ____
- ❍ SLR is real but do not agree with the rate estimated by IPCC (please explain) _________________
- ❍ Other (please explain) ____

32- Is it important to determine the carrying capacity of the islands before type of measures are being decided?

- Yes
- No (please explain) ____

33- Are dynamites or other explosives being used in blasting hard strata in dredging projects in the Maldives?

- Yes
- No (please explain) ____

34- After the 97-98 El-Nino, what is your opinion about the rate of coral growth in the Maldives?

- Coral growth is satisfactory
- Coral growth unsatisfactory
- No progress at all
- Other (please explain) ____

35- Environmental Impact Assessments (EIA) are mandatory for all coastal protection projects in the Maldives. However, it is observed that monitoring during construction stage and evaluating impacts after project completion are not satisfactorily conducted in most projects. What could be done to make EIAs more result oriented?

____

36- Are there any environmentally friendly measures of coastline protection in the Maldives?

- Yes (please explain) ____
- No

37- From a scale of 0 to 3 (0=not applicable, 1=fairly important, 2=moderately important, 3=highly important) please provide a score for the importance of considering each of the factors in addressing technical viability aspect in the development of a coastal protection DSF for the Maldives?

_______ Constructability - Ease of construction
_______ Design reliability
_______ Maintenance - Simplicity of repair and maintenance
_______ Durability
_______ Quick construction
_______ Measures that minimise erosion down-drift
_______ Protection against wave direct attack
_______ Measures that require less skilled labour requirement
_______ Measures that require less machinery requirement

38- Provide a technical viability score from a scale of 0 to 3 (0=not applicable or very low, 1= fair, 2=good, 3=very good) for each of the coastal protection measures provided. (BW=Breakwater, SW=Seawall)

	Design reliability	Maintenance	Durability	Quick Construction	Less Erosion downdrift	Protect against wave attack	Less skilled labour required	Less machinery required
1 Rock Armour BW								
2 Tetrapod BW								
3 Coral mound BW								
4 Sand cement bags BW								
5 Geobags BW								
6 Steel piles BW								
7 Caisson BW								
8 Sand Cement bags-Revetment								
9 Concrete blocks-Revetment								
10 Reclamation								
11 Rock armours SW								
12 Concrete sheets SW								
13 Steel sheets SW								
14 Sand cement bags SW								
15 Gabions								
16 Sand cement bags-Groynes								
17 Coral mound-Groynes								
18 Geobags-Groynes								
19 Rock armours-Groynes								
20 Beach ridge								
21 Wetland/vegetation								
22 Beach nourishment								
23 Artificial Reefs								
24 Embankments								

39- Provide a multi-hazard resiliency score (how good the measure performs in each hazard) from a scale of 0 to 3 (0=not applicable or very low, 1= fair, 2=good, 3=very good) for each of the coastal protection measures provided (BW=Breakwater, SW=Seawall).

	Sea Level Rise	Tsunami	Earth Quake	Storm	Flooding	Coastal Erosion
1 Rock Armour BW						
2 Tetrapod BW						
3 Coral mound BW						
4 Sand cement bags BW						
5 Geobags BW						
6 Steel piles BW						
7 Caisson BW						
8 Sand Cement bags-Revetment						
9 Concrete blocks-Revetment						
10 Reclamation						
11 Rock armours SW						
12 Concrete sheets SW						
13 Steel sheets SW						
14 Sand cement bags SW						
15 Gabions						
16 Sand cement bags-Groynes						
17 Coral mound-Groynes						
18 Geobags-Groynes						
19 Rock armours-Groynes						
20 Beach ridge						
21 Wetland/vegetation						
22 Beach nourishment						
23 Artificial Reefs						
24 Embankments						

40- Provide a socio-aesthetics and environmental acceptability score from a scale of 0 to 3 (0=not applicable, 1=fairly important, 2=moderately important, 3=highly important) for the factors provided.

_______ Nature (the attractiveness of material)
_______ Landscape (aesthetics value to amenity)
_______ Non-navigational Hazard
_______ Not hazardous to people walking on them
_______ Does not limit view from upland areas
_______ Provide sheltered mooring areas
_______ Does not affect use of beach
_______ Does not impact land use (current and future)
_______ Provides more beach for recreation
_______ Provide improved additional marine life habitats
_______ Does not increase turbidity
_______ Material availability

41- Provide a socio-aesthetics and environmental acceptability score from a scale of 0 to 3 (0=not applicable or very low, 1= fair, 2=good, 3=very good) for each of the coastal protection measures provided. (BW=Breakwater, SW=Seawall)

	Aesthetics - Attractiveness of material	Landscape - Aesthetics value to amenity	Non-navigational Hazard	Not hazardous to people walking on them	Does not limit view from upland areas	Provide sheltered mooring areas	Does not affect use of beach	Does not impact land use (current and future)	Provides more beach for recreation	Provide improved additional marine life habitats	Does not increase turbidity	Material availability
1 Rock Armour BW												
2 Tetrapod BW												
3 Coral mound BW												
4 Sand cement bags BW												
5 Geobags BW												
6 Steel piles BW												
7 Caisson BW												
8 Sand Cement bags-Revetment												
9 Concrete blocks-Revetment												
10 Reclamation												
11 Rock armours SW												
12 Concrete sheets SW												
13 Steel sheets SW												
14 Sand cement bags SW												
15 Gabions												
16 Sand cement bags-Groynes												
17 Coral mound-Groynes												
18 Geobags-Groynes												
19 Rock armours-Groynes												
20 Beach ridge												
21 Wetland/vegetation												
22 Beach nourishment												
23 Artificial Reefs												
24 Embankments												

42- Please provide your comments regarding coastal protection measures in general in the Maldives, or about this survey. All remarks will be appreciated

____

43- Please provide the following information (this will help the researcher to contact you if further information or clarification is required)

- Name ____
- Designation ____
- Years of experience in the field ____
- Organisation/Company ____
- Email Address ____
- Date of Survey ____
-